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STUDIES IN ASTRONOMY

THE GREAT NEBULA IN ORION.

From a Photograph by W. E. Wilson, F.R.S.

STUDIES IN ASTRONOMY

BY

J. ELLARD GORE
F.R.A.S., M.R.I.A.
ASSOCIATE OF THE ASTRONOMICAL SOCIETY OF WALES
CORRESPONDING FELLOW OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

"Willst du ins Unendliche streiten,
Geh' nur in Endlichen nach allen Seiten."
GOETHE

LONDON
CHATTO & WINDUS
1904

"*Old Horace—'I will strike,' said he,*
'The stars with head sublime,'
But scarce could see, as now we see,
The man in Space and Time.
So drew perchance a happier lot
Than ours, who rhyme to-day.
The fires that arch this dusky dot—
Yon myriad-worlded way—
The vast sun-clusters' gathered blaze,
World-isles in lonely skies,
Whole heavens within themselves, amaze
Our brief humanities."

TENNYSON.

PREFACE

Most of the articles in the following pages have been published during the last few years in *The Gentleman's Magazine*, *Knowledge*, *The Observatory*, etc., and my thanks are due to the editors and publishers of these periodicals for permission to re-publish them. The articles have been carefully revised and partly re-written, and the information brought up to date. The following articles have not been previously published, "The Ring Nebula in Lyra," "The New Star in Perseus," and "The Coming Comet." For the illustrations my best thanks are due to Professor Barnard, D.Sc. of the Yerkes Observatory (U.S.A.), M. Henry, of the Paris Observatory, and Dr. W. E. Wilson, F.R.S.

J. E. G.

June, 1904.

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I

The Size of the Solar System

As my readers are doubtless aware, the solar system consists of a number of planets revolving round the sun as a centre, and of subordinate systems of satellites revolving round the planets, or at least round some of them. Our own earth is one of these planets, the third in order of distance from the central luminary, which forms the common source of light and heat to all the members of the system. In addition to the planets and satellites, there are also some comets which form permanent members of the solar system. Some of these comets revolve round the sun in very elongated orbits, while the planets and satellites revolve in nearly circular orbits. A consideration of the absolute size of this planetary system and its relative size compared with that of the universe of stars, or at least the universe visible to us, may prove of interest to the reader.

To determine the size of the solar system, it is, of course, necessary in the first place to ascertain the dimensions of the planetary orbits with reference to some standard, or unit of measurement, as it is termed. The unit of measurement adopted by astronomers is the sun's distance from the earth. As the earth is the third planet in order of distance from the sun, the distance is, of course, an arbitrary unit. We might take the mean distance of Mercury from the sun as the unit, but as we refer all our measurements to terrestrial standards, and the diameter of the earth is used in the measurement of the sun's distance, it is found more convenient to take the earth's distance from the sun as the standard of measurement for the solar system and the distance of the stars.

The relative distances of the planets from the sun have been determined by astronomical observations, and are represented approximately by the following figures, the earth's mean distance from the sun being taken as unity: Mercury, 0·387; Venus, 0·723; the earth, 1·0; Mars, 1·523; the minor planets, 1·946 to 4·262; Jupiter, 5·2028; Saturn, 9·538; Uranus, 19·183; and Neptune, 30·055; or taking the earth's mean distance from the sun as 1000, the distance of Mercury will be represented by 387; Venus, 723; Mars, 1523; the minor planets, 1946 to 4262; Jupiter, 5203; Saturn, 9538; Uranus, 19,183; and Neptune, 30,055. These are the mean or average distances, the orbits not being exact circles, but ellipses of various eccentricities, that of Mercury—among the large planets—being the most eccentric, and that of Venus the least so. Among the minor planets the eccentricities vary from 0, or a perfect circle, to 0·38, the value found for a small planet discovered by Stewart in August, 1901.

The first scientific attempt to determine the sun's distance from the earth seems to have been made by Aristarchus of Samos. His method was to note the exact time when the moon is exactly half full, and then to measure the apparent angle between the centres of the sun and moon. It is evident that when the moon is half full, the earth and sun, as seen from the moon, must form a right angle with each other, and if we could then measure the angle between the sun and moon, as seen from the earth, all the angles of the right-angled triangle formed by the sun, moon, and earth would be known, and we could deduce at once the relative distances of the sun and moon from the earth. This method is, of course, perfectly correct in theory, but in practice it would be impossible, even with a telescope, to determine the moment when the moon is *exactly* half full, owing to the irregularities of its surface. Aristarchus had no accurate instruments, and no knowledge of modern trigonometry, but by means of a tedious geometrical method he concluded that the sun is 19 times further from the earth than the moon. This result is now known to be far too small, the sun's distance from the earth being in reality about 388 times the moon's distance.

In modern times the sun's distance has been determined by various methods. The most recent results tend to show that the sun's parallax, as it is termed, cannot differ much from 8·80 seconds of arc. The solar parallax is the angle subtended at the sun by the earth's semi-diameter. A parallax of 8·80 seconds implies that the earth's mean distance from the sun is about 92,800,000 miles. Multiplying this number by the figures given above, we find that the mean distances of the planets from the sun are as follows, in round numbers: Mercury, 35,913,000 miles; Venus, 67,094,000; Mars, 141,334,000; the minor planets, 193,024,000 to 395,513,000; Jupiter, 482,838,000; Saturn, 885,126,000; Uranus, 1,780,182,000; and Neptune, 2,789,104,000. This makes the diameter of the solar system, so far as at present known, about 5578 millions of miles. Across this vast distance light, travelling at the rate of 186,300 miles a second, would take 8 hours 19 minutes to pass.

But vast as this diameter really is compared with the size of our earth, or even with the distance of the moon, it is very small indeed when compared with the distance of even the nearest fixed star, from which light takes over four years to reach us. The most reliable measures of the distance of Alpha Centauri, the nearest of the fixed stars, places it at a distance of 275,000 times the sun's distance from the earth, or about 9150 times the distance of Neptune from the sun. If we represent the diameter of Neptune's orbit by a circle of 2 inches in diameter, Alpha Centauri would lie at a distance of 762 feet, or 254 yards, from the centre of the small circle. If we make the circle representing Neptune's orbit 2 feet in diameter, then Alpha Centauri would be distant from the centre of this circle 9150 feet, or about $1\frac{3}{4}$ mile. As the volumes of spheres vary as the cubes of their diameters, we have the volume of the sphere which extends to Alpha Centauri 766,000 million times the volume of the sphere containing the whole solar system to the orbit of Neptune. If we represent the sphere containing the solar system by a grain of shot $\frac{1}{20}$ inch in diameter, the sphere which extends to Alpha Centauri would be represented by a globe 38 feet in diameter.

It will thus be seen what a relatively small portion of space the solar system occupies, compared with the sphere which extends to even the nearest star. But this latter sphere, vast as it is, is again relatively small compared with the size of the sphere which contains the great majority of the visible stars. Alpha Centauri is an exceptionally near star. Most of the stars are at least ten times as far away, and possibly many a hundred times further off. A sphere with a radius a hundred times greater than the sphere containing Alpha Centauri would have a million times the volume, and therefore 766,000 *billion* times the volume of the sphere which contains the whole solar system!

From these facts it will be seen that, enormously large as the solar system absolutely is compared with the size of our own earth, it is, compared with the size of the visible universe, merely as a drop in the ocean.

The sun is usually considered as a body of enormous size. And so it is. It is over 1,300,000 times larger than the earth, and nearly 1000 times the size of the "giant planet" Jupiter. Yet, compared with the sphere containing the solar system, its volume is insignificant. Taking its diameter at 866,000 miles, I find that the volume of a sphere having the same diameter as the orbit of Neptune would be over 267,000 million times the sun's volume!

II

Jupiter and its System

JUPITER has been well termed the "giant planet" of the solar system, exceeding as it does, both in volume and mass, all the other planets put together. Its volume and mass are variously stated in works on astronomy. I find that the volume given in different books ranges from 1200 to 1387 times the volume of the earth. This discrepancy probably arises, in some cases at least, from assuming the planet to be a perfect sphere, whereas it is considerably flattened at the north and south poles—much more so than our globe. Recent measures by Prof. Barnard, of the Lick Observatory, make the equatorial diameter 89,790 miles, and the polar diameter 84,300 miles. Assuming these dimensions for Jupiter, and for the earth those given by Harkness, namely, 7926·248 and 7899·844 miles respectively, I find that—assuming both bodies to be oblate spheroids—the volume of Jupiter's globe is 1369·4 times the volume of the earth. According to Harkness, the sun's mass is 327,214 times the mass of the earth, and 1047·55 times that of Jupiter. Hence it follows that Jupiter's mass is 327,214 divided by 1047·55, or 312·36 times the mass of the earth. Its density or specific gravity, compared with that of the earth, will therefore be 312·36 divided by 1369·4, or 0·228, that of the earth being 1. Assuming the earth's density at 5·576, as found by Harkness from a discussion of various measures, the density of Jupiter will be 1·27 (water = 1), or a little less than that of the sun, which is about 1·40.

From the measures given above, the mean diameter of Jupiter is 87,045 miles, or eleven times that of the earth, and about one-tenth of the sun's diameter.

Taking the earth's mean distance from the sun at 92,796,950 miles, as given by Harkness, the mean distance of Jupiter from the sun will be 482,803,970 miles. The eccentricity of its elliptical orbit being 0·04825, its distance from the sun at perihelion is about 459,507,760 miles, and at aphelion 506,100,180 miles. Between its greatest and least distance, therefore, there is a difference of 46,592,420 miles, or about one-half the earth's mean distance from the sun. The inclination of Jupiter's orbit to the plane of the ecliptic being only 1° 18′ 41″—or less than that of any of the large planets, with the exception of Uranus—the planet never departs much from the Ecliptic, and hence it was called by the ancients "the Ecliptic planet." Its period of revolution round the sun is 11 years 314·8 days. The inclination of the axis of rotation being nearly at right angles to the plane of its orbit, there are practically no seasons in this distant world, and the only variation in the heat and light at any point on its surface would be that due to the comparatively small variation in its distance from the sun referred to above. Its mean distance from the sun being 5·2028 times the earth's mean distance from the sun, it follows that the heat and light received by Jupiter is twenty-seven times (5·2 squared) less than the earth receives. Thus it will be seen that the amount of heat received by this planet from the sun is very small, and were it constituted like the earth, its surface should be perpetually covered with frost and snow. Far from this being the case, the telescope shows its atmosphere to be in a state of constant and wonderful change. These extraordinary changes cannot possibly be due to the solar heat, and they have suggested the idea that the planet may perhaps be in a red-hot state, a miniature sun, in fact, glowing with inherent heat. The great brilliancy of its surface, the "albedo," as it is called, and its small density—less than that of the sun—are facts in favour of this hypothesis. As the attraction of Jupiter's enormous mass would render the materials near its centre of much greater density than those near its surface, the latter must be considerably lighter than water, and may possibly be in the gaseous state.

It has been objected to this hypothesis of inherent heat in Jupiter that the satellites totally disappear when they pass into the shadow of the planet and are eclipsed, as they frequently are, and that if they received any light from Jupiter they should remain visible in large telescopes when eclipsed. This objection is not so plausible as it may at first sight appear. The *light* afforded by Jupiter to his satellites when eclipsed may be small, although the *heat* of the planet may be comparatively great. Red-hot iron, although at a very high temperature, does not give much light, and at the great distance the satellites are from the earth the light they receive from Jupiter might very well be quite imperceptible even in a large telescope. Possibly the "dark side" of Jupiter may appear to his satellites as our moon does when totally eclipsed and showing a ruddy light; and we know how little light the moon gives us during a total eclipse. There are several observations on record which seem to favour the hypothesis that the surface of Jupiter glows with inherent light in addition to the light it reflects from the sun. The famous observer, Cassini, once failed to find the shadow of the first satellite when it should have been on the disc. The shadow of the same satellite was seen grey by Gorton on one occasion. The shadow of the second satellite has been seen very indistinct by Buffham, Birt, and Grover, and it was seen grey by Flammarion and Terby in March, 1874. The well-known astronomer, Captain W. Noble, speaking of the chocolate colour of the second satellite's shadow when in transit in 1892, says, "The only feasible explanation of this appearance which occurred to me was that the portion of the planet's disc from which all sunlight was shut off was in a red-hot or glowing condition." The third satellite has been frequently seen in transit as a black spot, although fully illuminated by sunlight. This may be partly due, as has been suggested, to dark spots on the surface of the satellite; but the phenomenon of a "black transit" cannot be wholly due to this cause, for were the spots on its surface so very dark as this hypothesis would imply, they would also diminish the brightness of the satellite when seen on a dark sky. This is apparently not the case, for the third satellite is usually the brightest of all when observed outside the planet's disc.

In a paper on Planetary Atmospheres, by the Russian physicist Rogovsky, recently published,[1] he computes the temperature of Jupiter to be very high—between 1320° and 4060° of the Centigrade scale. He says, "All the observations confirm this. Thus Bond found the emissive power of its surface to be twice that of the best white-lead.

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[1] *Astrophysical Journal*, November, 1901.

It is, therefore, probable that *Jupiter* adds to the reflected sunlight light of its own. Bredikhin, on the basis of his many years' observation of the surface of *Jupiter*, Lohse, J. Scheiner, and others have enunciated the opinion that Jupiter is a glowing body." And again, "The dense and opaque atmosphere hides its glowing surface from our view, and we see, therefore, only the external surface of its clouds. The objective existence of this atmosphere is proved by the bands and lines of absorption in its spectrum."

The four well-known satellites of Jupiter were discovered by Galileo on January 7, 1610, and were some of the first-fruits of the invention of the telescope. They are usually known by the numbers I., II., III., IV., counting from the planet. Their distances from the centre of Jupiter are 266,400 miles, 423,800 miles, 676,000 miles, and 1,189,000 miles respectively, and their approximate diameters 2400, 2100, 3430, and 2930 miles. Satellite II. is therefore about the same size as our moon; I., a little larger; III., intermediate in size between Mercury and Mars; and IV., about the size of Mercury. Their periods of revolution round Jupiter range from $1^d\ 18^h\ 27\frac{1}{2}^m$ to $16^d\ 15^h\ 32^m$. Their density is small, that of I. being only a little greater than that of water; that of II. and III. about 2 (water = 1); and that of IV. about 1·47.

A fifth satellite was unexpectedly discovered by Prof. Barnard with the great Lick telescope on the night of September 9, 1892. This is a very faint and difficult object, shining only as a star of the 13th magnitude. Its distance from the centre of Jupiter is about 112,500 miles. It is therefore only 67,600 miles from the surface of the planet, round which it revolves in the short period of $11^{h}\ 57^{m}\ 22\frac{2}{3}^{s}$, with a velocity of about $16\frac{1}{2}$ miles a second. It is too small for direct measurement, but, judging from its faintness, its diameter does not probably exceed 100 miles.

The rapid motion and change of phase of these satellites must form a most interesting spectacle in the sky of Jupiter. The rapidity of their motion is easily explained by the great mass of Jupiter. Were they to move as slowly as our moon does, they would soon fall on to the body of the planet. All the satellites, with the exception of the outer one, IV., are eclipsed at every revolution. Owing, however, to a remarkable relation which exists between the motions of the three other larger satellites, it follows that they can never be all eclipsed at the same time, so that there will always be more or less moonlight in the Jovian sky. The diameters of the discs of the large satellites, as seen from Jupiter's equator, will be 36, $18\frac{1}{2}$, 18, and $8\frac{1}{2}$ minutes of arc respectively. Satellite I. would therefore show a disc somewhat larger than our moon, and the others smaller. Barnard's satellite would have a disc of about 5 minutes in diameter. The combined light of the satellites, however, as seen from Jupiter, is, owing to their great distance from the sun, considerably less than that we receive from our solitary moon. But Jupiter himself must afford a considerable amount of light to the satellites at night. From satellite I. he appears as a disc of about 19 degrees in diameter; from II., about 12 degrees; from III., over 7 degrees; and from satellite IV., over 4 degrees. Jupiter's light on all the satellites, especially on I. and II., must therefore much exceed that of our full moon. But if the illumination of their nights is good, their daylight is not quite so satisfactory. Total eclipses of the sun by Jupiter are of almost daily occurrence, those seen from the first satellite lasting nearly $2\frac{1}{2}$ hours, and from the fourth over $4\frac{1}{2}$ hours.

Seen from Barnard's satellite, I find that Jupiter would show an enormous disc, of which the equatorial diameter would be about 47 degrees, and the polar about 44 degrees. From the proximity of this little satellite to the surface of Jupiter, and the great velocity of its rotation round the planet, we may deduce some curious and interesting facts connected with it. In the first place, as the satellite is comparatively so close to the surface of the giant planet, and revolves round it nearly in the plane of Jupiter's equator, the satellite will not be visible from higher Jovian latitudes than about 65 degrees north and south. Residents[1] in Jupiter nearer to the poles would therefore know less about this tiny satellite than even we do, except, perhaps, by the reports of those who had visited lower latitudes. Again, the period of Jupiter's rotation on its axis being about $9^h\ 55^m\ 37^s$, and the period of revolution of the fifth satellite about 12 hours, it follows that five revolutions of the satellite are nearly equal to six rotations of Jupiter. From this relation, I find that the satellite will remain above the horizon of any spot on Jupiter's equator for about 23 hours, and remain below the horizon about 37 hours. During the time, therefore, that the satellite is visible in the sky of Jupiter it makes nearly two revolutions round the planet's centre, and will go twice through all its phases, which are similar to those of our moon. This apparent anomaly is due to the fact that the motion of revolution of the satellite and that of the rotation of the planet are in the same direction, namely, from west to east, and that the periods do not differ very much in length.

Some idea may be gained of the relative size of the giant planet and its tiny acolyte by supposing the satellite to be represented by a grain of shot of one-tenth of an inch in diameter. Jupiter will then be represented by a globe 87 inches, or 7 feet

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[1] That is, were life possible on Jupiter, which, of course, is not the case.

3 inches, in diameter! As the volumes of spheres vary as the cubes of their diameters, the volume of Jupiter will be about 680,000,000 times the volume of the little satellite.

The light afforded by Jupiter to its little satellite must be very considerable. Taking the diameter of Jupiter as seen from the satellite at 45 degrees, the area of its disc would be about 8000 times the apparent area of our full moon. Of course, the intensity of sunlight on Jupiter is 27 times less than that of sunshine on the moon, but, on the other hand, Jupiter's "albedo," or light-reflecting power, is very high, probably about four times that of the moon. The brightness of Jupiter's surface will therefore be $\frac{4}{27}$ of the brightness of the moon's surface. Hence we have the light afforded by Jupiter to the little satellite equal to $8000 \times \frac{4}{27}$, or over 1100 times the light of our full moon.

III

Giant Telescopes

THE invention of the telescope is ascribed by Borelli, a Dutch mathematician, to Zachariah Jansen and Hans Lipperscheim, spectacle-makers, residing in Middleburgh, Holland, about the year 1600. The news of the invention did not spread rapidly, and was unknown to Galileo until the year 1609. In that year the famous Italian astronomer, having learned the principles of its construction, set to work and succeeded in making one which magnified three times—about the power of a modern opera-glass. He afterwards succeeded in constructing one which magnified thirty times, and the reward of his efforts was, as is well known, the discovery of the satellites of Jupiter, the phases of Venus, the spots on the sun, etc. Galileo's telescopes were made on the principle of the opera-glass and binocular field-glass, namely, with a convex object-glass and a concave eye-piece, both being single lenses. The great objection to this form of telescope, with single lenses, is due to what is called "chromatic aberration," which produces a fringe of colour round the objects viewed. This colouring interferes greatly with clear vision. Take an inferior opera-glass, or cheap hand telescope, and look at a range of hills projected against a background of white clouds. Along the "sky-line" of the hills will be seen a rainbow-tinted fringe, which prevents the outline of the hills being seen sharply defined as it would appear in a really good telescope. This defect, annoying as it is with terrestrial objects, is especially so when we view celestial objects like the moon and planets. To get rid of this imperfection—at least, to some extent—the old telescope-makers had recourse to instruments of enormous length. The famous Hevelius, the astronomer of Dantzic, constructed one of 150 feet in length, the tube, or rather skeleton tube, being made of planks, and suspended by ropes to a strong mass fixed in the ground. By a very ingenious system of ropes and pulleys, he succeeded in keeping this unwieldy affair tolerably straight and steady. He suggested that it would be a better arrangement to have the apparatus attached to a revolving tower, but want of means prevented him from carrying out this plan. Campani, of Bologna, constructed a similar telescope of 136 feet long in 1672, and Huygens one of 123 feet, which is still preserved by the Royal Society. Bradley measured Venus in 1722 with a telescope 212 feet long, and Auzot is said to have constructed one of 600 feet, which, however, he could not use, owing to its enormous length. These huge instruments were, however, gigantic only in length, their diameter being only a few inches. One of Campani's, preserved by the Royal Astronomical Society, has an object-glass of only 2 inches in diameter. A modern telescope 6 feet long would probably be superior in every way to the largest of these old instruments.

Sir Isaac Newton made several experiments with a view to the improvement of refracting telescopes, but came to the conclusion that it was impossible to get rid of the chromatic aberration produced by lenses. He then turned his attention to the construction of telescopes with metallic mirrors — first suggested by James Gregory, a Scotchman, in 1663—and succeeded in making several which gave satisfactory results. In this form of telescope the image, being formed by reflection, is free from colour. Newton's telescopes were, however, very small, and only a few of any size were constructed for about a hundred years, when Sir William Herschel took up the subject, and succeeded in constructing several reflecting telescopes of considerable size, his largest being no less than 4 feet in diameter. This great instrument was finished in the year 1789, and with it the illustrious astronomer discovered the two small satellites of Saturn, Mimas and Euceladus. In after years a reflecting telescope of 4 feet in diameter and 40 feet long was constructed by Mr. Lassell, who took it to Malta, and with it discovered numerous nebulæ.

These telescopes were, however, soon exceeded in size by Lord Rosse's famous instrument of 6 feet in diameter, completed in 1845. This giant telescope, which is still the largest in the world, is 52 feet in length. The tube, 7 feet in diameter, is formed of wood, strengthened with iron hoops. There are two mirrors, one weighing 3½ and the other 4 tons. The metal of which they are made is an alloy of copper and tin in the proportion of 126 parts copper to 57½ of tin. As the telescope is fixed between two high walls running north and south, observations can only be made when objects are near the meridian.

These large metallic mirrors, although of great light-grasping power, are deficient in definition, and are said to "bunch bright stars into a cocked hat!" A German astronomer, having looked through Lord Rosse's telescope, afterwards said, "They showed me something which they said was Saturn, and I believed them." Another objection to these telescopes is that the metallic mirror rapidly tarnishes, and has to be repolished. It may be imagined that this operation, in the case of a mirror weighing 4 tons, is a matter of no small difficulty.

Metallic mirrors have, in recent years, been superseded by mirrors made of glass. The glass disc is first carefully ground to the proper curved surface. This surface is then covered with a thin coating of silver by a chemical process, and this silver film is then polished. These mirrors reflect much more light, and give much better definition than the old metallic mirrors. They are, of course, liable to tarnish also after being some years in use, but they can be re-silvered and polished with very little expense and trouble. These "silver-on-glass" mirrors have recently come into great favour, and, being much cheaper than refractors of equal power, they are very popular among amateur astronomers. Some very large telescopes of this kind have been constructed in recent years. One of 3 feet in diameter was made by Calver in 1879. It is now at the Lick Observatory, and with it some fine photographs of stars and nebulæ have been taken. There is another of 4 feet diameter in the Paris Observatory, constructed by Martin. One of 5 feet in diameter was made by the late Dr. Common, and proved very satisfactory. This telescope is probably equal, if not superior, both in light and power, to Lord Rosse's telescope. Another of 5 feet aperture, made by Mr. G. W. Ritchey in 1902, is at the Yerkes Observatory (U.S.A.). Larger telescopes of this class are contemplated, glass mirrors of even 8 and 10 feet being now spoken of as possible in the near future.

Although Sir Isaac Newton despaired of any improvement in refracting telescopes which would get rid of the chromatic aberration, the problem was not abandoned as hopeless, and in the year 1729 — two years after Newton's death — Mr. Chester More Hall, considering the construction of the human eye, succeeded in obtaining a combination of lenses of different kinds of glass which gave an image free from colour. This was the origin of the achromatic telescope, as it is called, which has made such rapid progress in recent years. The combination of lenses now employed was devised in 1758 by the famous optician, John Dollond, and to him is often ascribed the invention of the achromatic telescope, but the credit of the invention is really due to More Hall. In 1765 John Dollond's son, Peter Dollond, discovered that the chromatic aberration could be further reduced by a combination of three lenses instead of two. This form of object-glass is still sometimes used in binoculars, but for large telescopes two lenses only are generally used.

Notwithstanding this great improvement in the construction of refracting telescopes, many years elapsed before telescopes of any size were constructed on this principle. Even in the year 1825 the largest telescope of this kind was one of only 9½ inches in diameter, constructed by the famous optician, Fraunhofer, for the Dorpat Observatory, Russia. M. Struve, the director of the observatory, wrote with reference to it, "I stood astonished before this noble instrument, undetermined which to admire most—the beauty and elegance of the workmanship in its most minute parts, the appropriateness of its construction, the ingenious mechanism for moving it, or the incomparable optical power of the telescope, and the precision with which objects are defined." Astronomers of the present day would hardly call a telescope of this size "a noble instrument," refractors of 8 to 10 inches in diameter being now comparatively numerous. Struve, however, did excellent work with this instrument, and discovered and catalogued hundreds of double stars, a good example of what has been said with reference to telescopes in general, that the work done with any instrument "does not depend so much on the diameter at the big end as on the man at the small end."

Gradually, however, refracting telescopes increased in size. In 1834 an achromatic of 11½ inches aperture and 19 feet in length was constructed by Cauchoix, and mounted in the Cambridge Observatory. This is known as the Northumberland Equatorial, and was so named after the Duke of Northumberland, who presented it to the observatory. In the same year a refractor of 13¼ inches aperture and 25½ feet long, by the same maker, was mounted at the observatory, Markree Castle, Ireland, by the late E. J. Cooper. There is also a refractor by Cauchoix of 11·8 inches aperture at Dunsink Observatory, Dublin, and there are several of from 12 to 13½ inches in the United States and elsewhere. At the Poulkova Observatory, Russia, there is a fine refractor of 15 inches aperture and 22½ feet focus, the work of Merz and Mahler. The weight of this instrument is 7000 lbs., or over 3 tons. It has a series of eye-pieces, the highest magnifying about 2000 times. The Harvard College Observatory, U.S.A., has a telescope of the same size and by the same makers as the Poulkova telescope. The Paris Observatory has also a refractor of 15 inches diameter, but it is not a very good one. The following observatories also possess refractors of about 15 inches aperture: Milan, Stonyhurst, Rio Janeiro, Madrid, Brussels, Edinburgh, and Tulse Hill (Dr. Huggins). The Harvard College telescope at one time shared with the Poulkova refractor the honour of being the largest refractor in the world. With it Bond, the famous American astronomer, discovered, in September, 1848, Hyperion, the 8th satellite of Saturn (discovered independently, a few days later, by Lassell in England). With it, also, Bond discovered the dark or "crape" ring of Saturn, which was also independently discovered by Dawes in England. Bond's great drawing of the Orion nebula was also made with this telescope.

Dr. Cerulli has a refractor of 15½-inch aperture at his observatory, Peramo, Italy, and there are others of about the same size at the Washburn

Observatory (U.S.A), and at the Meudon Observatory. Mr. Warner, of "Safe Cure" fame, has one of 16 inches at his private observatory, Rochester (U.S.A.). Professor Max Wolf has one of 16 inches at Heidelbergh, and there is another of about the same aperture at the Goodsell Observatory (U.S.A.). Telescopes of 16½ inches aperture are at Zi-ka-Wei, Vienna, and Nice, and 18-inch refractors at the Royal Observatory, Cape of Good Hope; the Vander Zee Observatory; the Flower Observatory (U.S.A.); the Lowell Observatory, Mexico; and the National Observatory, La Plata.

At the Dearborn Observatory, Chicago, there is a telescope of 18½ inches aperture, with which Burnham has done such excellent work among the double stars. It was with this instrument that Alvan Clark discovered the companion to Sirius before the telescope left his workshop. This was for ten years the largest refractor in the world.

The observatory at Milan has a refractor of 19·1 inches, by Merz, and there is another of about the same size at the Imperial Observatory, Strassburgh.

There is one of 20 inches aperture at the Manila Observatory, and another at the Chamberlin Observatory, Colorado.

We now come to refractors of over 20 inches aperture, and the following list includes all those at present in existence:—

1. Refractor of 20·5 inches aperture, private observatory of M. Porro, Italy.

2. Refractor of 21·2 inches, constructed by Buckingham and Wragge for Mr. Buckingham's private observatory.

3. Refractor of 21·8 inches, by Merz, at the Etna Observatory.

4. Object-glass of 22 inches, at the Edinburgh Observatory.

5. Refractor of 23 inches, constructed by Alvan Clark for the Halsted Observatory, Princeton (U.S.A.).

6. Refractor of 23·6 inches, National Observatory of Paris; constructed by Brothers Henry and Gautier, 1891.

7. Refractor of 24 inches, by Alvan Clark (1896), Lowell Observatory, Mexico.

8. Photographic refractor of 24 inches, Royal Observatory, Cape of Good Hope; the work of Sir Howard Grubb, and another by the same eminent maker at the Radcliffe Observatory, Oxford.

9. Photographic refractor of 24 inches, by Alvan Clark (1893), at the Harvard College Observatory (U.S.A.). The focal length is only 11·3 feet. It was presented to the observatory by Miss Bruce.

10. Refractor of 24·4 inches, National Observatory, Meudon; made by Henrys and Gautier (1891). This is also a photographic telescope.

11. Refractor of 25 inches aperture, made by

Cooke of York (1870) for the late Mr. Newall. Now at the Cambridge Observatory.

12. Refractor of 26 inches, made by Alvan Clark (1881) for the private observatory of Mr. Leander McCormick at Virginia (U.S.A.). With this instrument numerous measures of double stars have been made by Messrs. Leavenworth and Muller.

13. Refractor of 26 inches, also constructed by Alvan Clark (1873), for the Washington Observatory (U.S.A.). With this "noble" instrument Professor Asaph Hall discovered the two satellites of Mars in 1877, and has made numerous observations of double stars. In the object-glass of this telescope the thickness of the crown lens is 1·88 inch, and that of the flint lens 0·96 inch.

14. Photographic refractor of 26 inches, at the Royal Observatory, Greenwich; the work of Sir Howard Grubb. The focal length is 26 feet.

15. Refractor of 27 inches, at the Imperial Observatory, Vienna; constructed by Sir Howard Grubb. This telescope has been chiefly used in the search for minor planets between Mars and Jupiter.

16. Refractor of 28 inches, Royal Observatory, Greenwich; also made by Sir Howard Grubb.

17. Refractor of 28·9 inches, at the National Observatory, Paris; made by Martin.

18. Refractor of 30 inches, constructed by Alvan Clark (1888), for the Poulkova Observatory, Russia.

19. Refractor of 30·3 inches, at the Bischoffsheim Observatory, Nice; the work of the Brothers Henry and Gautier.

20. Photographic refractor of 31·5 inches, at the Astrophysical Observatory, Potsdam; made by Steinheil and Repsold, 1899.

21. Refractor of 32·5 inches, at the National Observatory, Meudon; made by the Brothers Henry and Gautier, 1891.

22. The great telescope of the Lick Observatory, California. This magnificent instrument has an object-glass of 36 inches aperture and 57·8 feet focal length, the work of Alvan Clark and Sons, the mounting being constructed by Warner and Swasey. The Lick observatory was founded by the late Mr. Lick, a retired piano and organ maker, of Baltimore, who made an enormous fortune by land speculations, most of which he left for public purposes. The observatory is situated on the summit of Mount Hamilton, at a height of 4200 feet above the level of the sea, and about 60 miles south-east of San Francisco. The tube of the great telescope is 57 feet long, or about 5 feet longer than Lord Rosse's giant reflector. The telescope is fitted with "finders" of 3, 4, and 6 inches aperture. The largest of these would have been considered a fairly large telescope at the beginning of the nineteenth century. The telescope is sheltered by a dome of 75 feet in diameter, weighing nearly 89 tons,

and resting on a brick wall 25 feet high. Surrounding the pier which carries the telescope is a floor which is raised and lowered by hydraulic power to suit the varying height of the eye-piece. Although this moving floor weighs over 22 tons, it can be raised in nine minutes. In addition to the object-glass, the telescope is supplied with a photographic lens of 33 inches aperture and 49·2 feet focus, with which some fine photographs of the moon and other celestial objects have been made. Although this giant telescope has only been in use for a few years, much excellent work has been done with it. By its aid Barnard discovered the fifth satellite of Jupiter, which is so faint that its existence was never suspected with any of the large telescopes with which the planet has been frequently observed. Numerous measures of close double stars have also been made with it by Burnham, who has added so much to our knowledge of these wonderful and interesting stellar systems. On the death of Mr. Lick, the founder of the observatory, the coffin containing his remains was built into the masonry pier which carries the telescope, the great instrument, with its surrounding dome, thus forming a fitting monument to his memory.

A refracting telescope of even larger dimensions than that of the Lick Observatory has been finished and mounted in a new observatory founded at Wisconsin, not far from Chicago, by

Mr. Yerkes, a wealthy American. The object-glass, which is 40 inches in diameter, with a focal length of 62 feet, was made by Alvan Clark, and has proved satisfactory. The convex lens of crown glass—that nearest the object—is about 3 inches thick in the centre and about $\frac{7}{8}$ inch at the edge, and weighs about 200 pounds. The concave or flint glass is about $1\frac{1}{2}$ inch at the centre and $2\frac{3}{4}$ inches at the edge, and weighs about 300 pounds. The mounting for this giant instrument was constructed by Warner and Swasey, and was exhibited at the Chicago Exhibition. The tube is of sheet steel, and weighs about 6 tons! The total weight of the telescope and mounting is about 75 tons! The driving-clock alone weighs about $1\frac{1}{2}$ ton! The dome covering the telescope is 80 feet in diameter!

With reference to the largest-sized refractor which can be made, it appears that we have not yet reached the limit for this form of telescope. Mr. Clark expressed his opinion that, notwithstanding the absorption of light due to the increased thickness of the lenses necessary in these large telescopes, their light-grasping power has hitherto increased in proportion to their size. He considered that the 30-inch object-glass which he made for the Poulkova Observatory is "vastly superior" to the 26-inch Washington refractor; that the 36-inch Lick telescope is "certainly superior to the 30-inch;" and he had "every reason to suppose that the 40-inch will be superior to the 36-inch." If this be so, we may expect interesting celestial discoveries with the great 40-inch Yerkes telescope. Mr. Clark's anticipations have already been partially realized.

IV

The Distances of the Stars

THE determination of the distance of the stars from the earth has always formed a subject of great interest to astronomers in all ages. The old astronomers seem to have considered that the problem was incapable of solution. In later years the famous astronomer Kepler, judging from what he termed "the harmony of relations," concluded that the distance of the fixed stars should be about 2000 times the distance of Saturn from the sun. At that time Saturn was the farthest known planet of the solar system. But the distance of even the nearest star, as now known, is about 14 times greater than that supposed by Kepler. Huygens thought the determination of a star's distance by direct observations to be impossible, but made an attempt at a solution of the problem by a photometric comparison between Sirius and the sun. By this method of estimation he found that Sirius is probably about 28,000 times the sun's distance from the earth. Modern measures, however, show that this estimate is also far too small, the distance of Sirius, as now known, being over 500,000 times the sun's distance, or about 18 times greater than Huygens made it.

When the Copernican theory of the earth's motion round the sun was first advanced, it was objected that if the earth moved in an orbit round the sun, its real change of place should produce an *apparent* change of position in the stars nearest to the earth, causing them to shift their relative position with reference to more distant stars. Copernicus replied to this objection —and we now know that his reply was correct— by saying that the distance of even the nearest stars is so great that the earth's motion would have no perceptible effect—at least, to the naked eye—in changing their apparent position in the heavens. In other words, the diameter of the earth's orbit round the sun would be almost an imperceptible point if viewed from the distance of the nearest stars. This explanation of Copernicus was at first ridiculed, and even the famous astronomer, Tycho Brahé, could not accept such a startling hypothesis. This celebrated observer failed, indeed, to detect by his own observations any annual change of place, but he fancied that the brighter stars showed a perceptible disc—like the planets—a fact which, if true, would imply that, if the distance was so great as Copernicus supposed, the real size of the stars must be enormous. Tycho Brahé estimated that stars of the 1st magnitude have an apparent diameter of 120 seconds of arc, those of the 2nd magnitude 90 seconds, and that stars of even the 6th magnitude would have a diameter of about 20 seconds. But this delusion of Tycho Brahé has been dispelled by modern observations, which show that even the brightest stars have no perceptible disc. This fact was also proved by Horrocks and Crabtree, who noticed that in occultations of stars by the moon the stars disappeared instantaneously, a fact which proved beyond a doubt that the apparent diameter of the stars must be a very small fraction of a second. We now know that the apparent diameter of even the nearest star, α Centauri, cannot exceed the $\frac{1}{100}$th of a second.

The first idea which naturally suggested itself with reference to the distances of the stars was that the brightest stars were the nearest, and the faintest the farthest from the earth, an idea based, of course, on the assumption that the stars are in general of nearly the same size and intrinsic brilliancy. This hypothesis, although apparently a very reasonable one, has been found by modern researches to have, strange to say, little or no foundation in fact. Although this hypothesis is now proved to be erroneous, it may be interesting to inquire what the relative distances of the stars would be on the assumption of equal size and brightness. To enable us to answer this question, we must first consider the subject of "star magnitudes." The stars were divided by the ancient astronomers into "magnitudes," according to their relative brightness; all the brightest being placed in the 1st magnitude, those considerably fainter being called 2nd magnitude, those fainter still 3rd magnitude, and so on to the 6th magnitude, or those just visible to ordinary eyesight. This classification has been practically retained by modern astronomers, but, of course, there are stars of all degrees of brightness, from Sirius down to the faintest visible in the largest telescopes. Sirius is the brightest star in the heavens, and is about equal to eleven average stars of the 1st magnitude, such as Aldebaran. According to the Harvard photometric measures, the following are the brightest stars in the heavens, in order of brightness: (1) Sirius, (2) Canopus, (3) α Centauri, (4) Vega, (5) Capella, (6) Arcturus, (7) Rigel, (8) Procyon, (9) Achernar, (10) β Centauri, (11) Betelgeuse (slightly variable), (12) Altair, (13) α Crucis, and (14) Aldebaran. Of these, Canopus, α and β Centauri, and Achernar do not rise above the English horizon. Of the stars brighter than the 2nd magnitude, the following are north of the equator: Pollux, α Cygni, Regulus, Castor, ε Ursæ Majoris, γ Orionis, β Tauri, α Persei, η Ursæ Majoris, γ Geminorum, and α Ursæ Majoris; and south of the equator: Spica (α Virginis), Antares, Fomalhaut, β Crucis, γ Crucis, ε Canis

Majoris, λ Scorpii, ε Argûs, ε Orionis, β Argûs, α Trianguli Australis, ζ Orionis, ε Sagittarii, δ Canis Majoris, and β Canis Majoris. Of those below the 2nd magnitude, but brighter than 3·0, there are 46 in the northern hemisphere, and 58 in the southern. As the brightness diminishes, the numbers increase very rapidly. Indeed, the increase is in geometrical progression; the number of stars in each class of magnitude being from three to four times as many as those in the class one magnitude brighter. At least, this is the case down to a certain point, where a "thinning out" seems to begin.

The difference of one magnitude between any two stars is defined by the "light ratio." This is "the ratio of the intensities of light which shall define the meaning of 'difference of a single magnitude' between the light of two stars." This ratio is now generally accepted by astronomers as 2·512; that is, a star of the 1st magnitude is assumed to be 2·512 times brighter than a star of the 2nd magnitude, a star of the 2nd magnitude 2·512 times brighter than a star of the 3rd magnitude, and so on. Hence, as light varies inversely as the square of the distance, the distance of any star—on the assumption of equal size and brightness—would be 1·585 (the square root of 2·512) times the distance of a star one magnitude brighter; and if we represent the distance of an average star of the 1st magnitude by 1, the following would be the relative distances of stars of various magnitudes: 1st magnitude, 1; 2nd magnitude, 1·585; 3rd magnitude, 2·512; 4th magnitude, 3·981; 5th magnitude, 6·31; 6th magnitude, 10; 7th magnitude, 15·849; 8th magnitude, 25·119; 9th magnitude, 39·811; 10th magnitude, 63·096; 11th magnitude, 100; 12th magnitude, 158·489; 13th magnitude, 251·189; 14th magnitude, 398·107; 15th magnitude, 630·957; and 16th magnitude, 1000. Or if, on a wide level plane, we take a fixed point, and assume the distance of a first magnitude star to be represented by 10 feet from this point, then the distance of a second magnitude star would be approximately 16 feet; 3rd magnitude, 25 feet; 4th magnitude, 40 feet; 5th magnitude, 63 feet; 6th magnitude, 100 feet; 7th magnitude, 158 feet; 8th magnitude, 250 feet; 9th magnitude, 398 feet; 10th magnitude, 631 feet; 11th magnitude, 1000 feet; 12th magnitude, 1585 feet; 13th magnitude, 2511 feet; 14th magnitude, 3981 feet; 15th magnitude, 6310 feet, or about 1·2 mile; and 16th magnitude, 10,000 feet, or nearly 2 miles. As, according to recent measures of parallax, light would take about 36 years to reach us from an average star of the first magnitude, it follows that the "light journey" from a star of the 16th magnitude (about the faintest visible in the great Lick telescope) would, on the above hypothesis, be about 36,000 years! Recent researches, however, have shown that some of the fainter stars are actually nearer to us than some of the brighter, and that, therefore, the brightness of a star is no criterion of its distance.

It was suggested by Galileo that the distance of the nearer stars might possibly be determined by careful measures of double stars, on the assumption that the brighter star of the pair, if the difference of brightness is considerable, is nearer to the earth than the fainter star. Acting on this suggestion, Sir William Herschel, at the close of the eighteenth century, made a careful series of measures of certain double stars. He did not, however, succeed in his attempt, as his instruments were not sufficiently accurate for such a delicate investigation; but his labours were abundantly rewarded by the great discovery of binary or revolving double stars, a most interesting class of objects. Numerous but unsuccessful attempts were also made by Hooke, Flamsteed, Cassini, Molyneux, and Bradley to find the distance of some of the stars. Hooke, in the year 1669, thought he had detected a parallax of 27 to 30 seconds of arc in the star γ Draconis, but we now know that no star in the heavens has anything like so large a parallax. It should be here explained that the "parallax" of a star is the apparent change in its position caused by the earth's annual motion round the sun. As the earth makes half a revolution in six months, and as its mean distance from the sun, or the radius of the orbit, is about 93 millions of miles, the earth is at any given time about 186 millions of miles distant from the point in its orbit which it occupied six months previously. The apparent change of position in a star known as parallax is *one-half* the total displacement of the star as seen from opposite points of the earth's orbit. In other words, it is the angle subtended at the star by the mean distance between the sun and earth. The measured parallax of a star may be either "absolute" or "relative." An "absolute parallax" is the actual parallax. A "relative parallax" is the parallax with reference to a faint star situated near a brighter star, the fainter star being assumed to lie at a much greater distance from the earth. As, however, the faint star may have a small parallax of its own, the "relative parallax" is the difference between the absolute parallaxes of the two stars. Indeed, in some cases a "negative parallax" has been found, which, if not due to errors of observation, would imply that the faint star is actually the nearer of the two. From the observed parallax the star's distance in miles may be found by simply multiplying the sun's distance from the earth—about 93 millions of miles—by the number 206265, and dividing the result by the parallax, or about 19 billions of miles, divided by the parallax in seconds. To find the time that light would take to reach us from the star—the "light-journey," as it is called—it is only necessary to divide the number 3·258 by the parallax. Thus, with a parallax of one second the "light-journey" would be 3¼ years; for a parallax of one-tenth of a second it would be 32½ years, and for a parallax of one-hundredth of a second nearly 326 years.

In attempting to verify the result found by Hooke for the parallax of γ Draconis, Molyneux and Bradley found an apparent parallax of about 20 seconds of arc, thus apparently confirming Hooke's result. But observations of other stars showing a similar result, Bradley came to the conclusion that the apparent change of position was not really due to parallax, but was caused by a phenomenon now known as the "aberration of light"—an apparent displacement in the positions of the stars, due to the effect of the earth's motion round the sun, combined with the progressive motion of light. The result is that "a star is displaced by aberration along a great circle of the star sphere, joining its true place to the point on the celestial sphere towards which the earth is moving." The amount of aberration is a maximum for stars lying in a direction at right angles to that of the earth's motion. The existence of aberration is a positive proof that the earth does revolve round the sun, for were the earth at rest—as some paradoxers maintain—there would be no aberration of the stars. This effect of aberration must, of course, be carefully allowed for in all measures of stellar parallax. To show that aberration could not possibly be due to parallax, it may be stated that aberration shifts the apparent place of a star in one direction, while parallax shifts it in the opposite direction.

From photometric comparisons, the Rev. John Michell, in the year 1767, concluded that the parallax of Sirius is less than one second of arc—a result which has been fully confirmed by modern measures. He considered that stars of the 6th magnitude are probably from 20 to 30 times the distance of Sirius, and, judging from their relative brilliancy, this conclusion would also be nearly correct, but modern measures have shown that the brightness of the stars is no test of their relative distance.

The stars on which observations were first made with a view to a determination of their distance seem to have been Aldebaran and Sirius. From observations made in the years 1792 to 1804, with a vertical circle and telescope of 3 inches aperture, Piazzi found for Aldebaran an absolute parallax of about one and a half second of arc. In 1857 Otto Struve and Shdanow, using a refractor of 15 inches aperture, found a "relative" parallax of about half a second. This was further reduced by Professor Hall, with the 26-inch refractor of the Washington Observatory, to about one-tenth of a second, and Dr. Elkin, with a heliometer of 6 inches aperture, finds a relative parallax of 0″·116, or about 30 years' journey for light. A parallax of about one-tenth of a second has also been recently found at the Yale University Observatory (U.S.A.). For Sirius, Piazzi found (1792–1804) an absolute parallax of 4 seconds, but this was certainly much too large. All subsequent observers find a much smaller parallax, recent results being a relative parallax of 0″·370 by Dr. Gill, and 0″·407 by Dr. Elkin. In the years 1802–1804 Piazzi and Cacciatori found an absolute parallax of 1″·31 for the Pole Star, but this has been much reduced by later observers. The late Professor Pritchard, by means of photography, found a relative parallax of only 0″·073, which agrees closely with some other previous results, and indicates a "light journey" of about 44 years! For the bright star Procyon, Piazzi found a parallax of about 3 seconds; but this is also much too large, a recent determination by Elkin giving 0″·325, a figure in fair agreement with results found by Auwers and Wagner. For the bright star Vega, Calandrelli, in the years 1805, 1806, found an absolute parallax of nearly 4 seconds; but this has been much reduced by modern measures, Elkin, from measures in the years 1887, 1888, finding a relative parallax of only 0″·034. For Arcturus, Brinkley found a parallax of over 1 second, but at Yale Observatory a parallax of 0″·024 was found. If this minute parallax is anything near the truth, Arcturus must be a sun of gigantic size.

Owing to the large "proper motion" of the star known as 61 Cygni, its comparative proximity to the earth was suspected, and in 1812 Arago and Mathieu found, from measures made with a repeating circle, a parallax of over one-half a second. Various measures of its parallax have since been made, ranging from about 0″·27 to 0″·566. Sir Robert Ball, when at Dunsink Observatory (Ireland), found 0″·468; and Prof. Pritchard, by means of photography with a 13-inch refractor, found 0″·437. These values have been somewhat reduced by recent measures, and we may, perhaps, assume that the parallax of 61 Cygni is about 0″·4, which gives a "light-journey" of about eight years. The star is only of the 5th magnitude. The small parallax found by Elkin for Arcturus would indicate a distance corresponding to a light-journey of 181 years, although the star is one of the brightest in the heavens. It is usually stated that 61 Cygni is the nearest star in the northern hemisphere; but for the star known as Lalande 21,185, Winnecke found a parallax of 0″·511, and afterwards 0″·501. This has, however, been reduced by Kapteyn (1885–87) to 0″·434. Recently a parallax of 0″·465 has been found by the photographic method for the binary star η Cassiopeiæ.

Nearer to us than 61 Cygni is the bright southern star α Centauri, which, so far as we know at present, is the nearest of all the stars to the earth. The first attempt to find its distance was made by Henderson, in the years 1832–1833, using a mural circle of 4 inches aperture and a transit of 5 inches. He found an "absolute parallax" of about one second of arc, which, however, subsequent measures have shown to be somewhat too large. Measures in recent years range from $0''\cdot512$ to $0''\cdot976$, but probably the most reliable are those made by Dr. Gill, who found a "relative parallax" of $0''\cdot75$. This result would place the star at a distance of 275,000 times the sun's distance from the earth, or about 25 billions of miles, a distance which light would take about $4\frac{1}{4}$ years to traverse.

Dr. Gill's researches on the distance of stars in the southern hemisphere reveal the remarkable fact that some of the brightest stars in the heavens lie at such a vast distance that attempts to measure their parallax have proved futile. Thus Canopus, the second brightest star in the sky, and not much inferior to Sirius in brilliancy, has absolutely no measurable parallax. The same result was found for Rigel, which is about seventh on the list of brightest stars, and also for β Crucis, one of the stars in the Southern Cross, of which the magnitude is 1·5. These must be suns of enormous size. For Spica, which is very little fainter than a standard star of the 1st magnitude, Dr. Gill finds a "negative parallax," which implies, if there is no error in the measures, that it is actually further from the earth than some faint stars near it. For Achernar (α Eridani), which is about the same brightness as Procyon, Dr. Gill finds a parallax of 0″·043, which implies a journey for light of about 76 years; and for α Gruis, of the 2nd magnitude, a parallax of only 0″·015, which indicates a light-journey of 217 years.

From the above results, it will be understood that the parallaxes found for even the nearest stars are so small that their exact determination taxes the powers of the most perfect instruments and the skill of the most experienced observers. One thing seems certain, however, that the brightest stars are not, as a rule, the nearest to the earth, and that even comparatively faint stars may be actually nearer to us than some of the brightest gems that deck our midnight sky.

When the distances of two stars from the earth have been accurately determined, the actual distance between the stars themselves can be easily computed by simple trigonometry. Take the case of Sirius and Procyon: the parallax of Sirius is 0″·37, and that of Procyon is 0″·325; and the apparent angular distance between the two stars is about 25° 43′. From these data I find that the actual distance between Sirius and Procyon is almost exactly half the distance which separates Sirius from the earth. From this it follows that the parallax of Procyon, seen from Sirius, or of Sirius, seen from Procyon, is about 0″·74. Hence the light of Sirius, seen from Procyon, will be increased four times, or about 1·50 magnitude; and its magnitude would therefore be −1·58 −1·50 = −3·08 magnitude. The light of Procyon, seen from Sirius, would be increased in the proportion of $\left(\frac{0{\cdot}74}{0{\cdot}325}\right)^2$, or 5·185 times. This corresponds to an increase of 1·78 magnitude. Hence the magnitude of Procyon, as seen from Sirius, would be 0·48 − 1·78 = −1·30, or nearly as bright as Sirius appears to us. Again, take the case of η and μ Cassiopeiæ, which are at an apparent distance of about 3° 50″. The parallax of each is about 0″·20. From these data I find that the real distance between the two stars would be only one-fifteenth of the distance which separates them from the earth, and the parallax of each, as seen from the other, would be three seconds of arc. Hence the brilliancy of each would be increased 225 times (15^2), or about 5·88 magnitudes. As the photometric magnitude of η Cassiopeiæ is 3·64, it would therefore shine as a star of −2·24 magnitude as seen from μ; and the magnitude of μ being 5·22, it would appear as a star of −0·66 magnitude as seen from η. But in this case the parallaxes are not so certain as in the case of Sirius and Procyon.

V

The Sun's Journey through Space

IT is now a well-established scientific fact that the sun, together with the earth and all the planets and satellites constituting the solar system, is speeding through space towards the constellation of the Lyre, and some account of the researches which have led to this result may prove of interest to the reader.

The ancient astronomers, who had no telescopes, and could only observe the heavens with the naked eye, thought that the constellations preserved through all ages the same forms and dimensions. Hence the term "fixed," which has been applied to the stars from the earliest times. To show this *apparent* fixity, we may mention the unchanged alignments frequently observed between three stars in various parts of the sky, which were noted by Ptolemy, and which still exist. There are many combinations of three stars nearly in a straight line. Twenty-five of these are noted by Riccioli. Of these may be mentioned the straight line formed by Aldebaran, ι Aurigæ, and Capella. ι Aurigæ, which is of the 3rd magnitude, lies nearly midway between the other two, which are 1st-magnitude stars. The three stars are, however, not exactly in a straight line, the middle star being distant more than half the moon's apparent diameter from the line joining the two brighter stars. But such a small difference would hardly be appreciable to the naked eye. Al-Sufi, the Persian astronomer, who wrote a "Description of the Fixed Stars" in the tenth century, also frequently speaks of three stars being in a straight line.

Even Copernicus and Kepler believed the stars to be absolutely fixed. Halley was the first who suspected—in 1718—that Aldebaran, Sirius, and Arcturus had a "proper motion," as it is termed, on the face of the sky; but to Cassini is due the credit of having proved beyond doubt the apparent motion of certain stars. Observations made by Ptolemy and other ancient astronomers were too rough to rely on for an accurate determination of the motions in question, so Cassini discarded them, and had recourse to more accurate observations made with the telescope. He therefore compared his own observations of Arcturus, made at the Paris Observatory in 1738, with those made by Richer at Cayenne in 1672. From these observations he found that, during the 66 years which had elapsed, this bright star had approached the ecliptic by nearly two minutes of arc, which gives an annual motion of about two seconds. Observations made by Flamsteed at Greenwich, in 1690, were also in favour of this apparent motion. To test the accuracy of his result, Cassini examined the observations made by Tycho Brahé in 1584—observations which, although made with the naked eye, were probably as accurate as they could possibly be without a telescope. He found that in the 154 years which elapsed between 1584 and 1738, the latitude of Arcturus, or its distance north of the ecliptic, had diminished by about five minutes of arc. This gives an annual motion of about two seconds of arc, thus agreeing closely with measures made with the telescope. Modern measures give Arcturus a "proper motion" of about 2·3 seconds of arc per annum. The neighbouring star, η Boötis, showed no such change in its apparent position on the celestial vault. Cassini also showed that Ptolemy's observations of Sirius, compared with those of Halley, gave a considerable "proper motion" to that brilliant star. Observations in recent years give a motion of about 1·32 seconds per annum.

Modern observations have revealed the existence of still larger "proper motions." Thus the small star, No. 1830 of Groombridge's catalogue (the so-called "runaway star"), has an annual proper motion of nearly 7 seconds of arc; Lacaille 9352, about 6·9 seconds; Cordoba 32416, 6·1 seconds; 61 Cygni, 5·2 seconds; Lalande 21,185, 4·7 seconds;

ϵ Indi, 4·6 seconds; μ Cassiopeiæ, 3·7 seconds; α Centauri, 3·7 seconds; and many others of smaller amount. Quite recently it has been found by Mr. Innes and Dr. Kapteyn that a star in the southern constellation, Pictor, has a proper motion of no less than 8·7 seconds per annum, a motion which would carry it through a space in the sky equal to the moon's apparent diameter in 214 years. The proper motions of over five thousand stars have now been accurately determined, and further researches may perhaps show that no really "fixed" star exists in the heavens.

Of twenty-five stars with proper motions exceeding two seconds of arc per annum, there are only two—α Centauri and Arcturus—whose magnitude exceeds the third. As a large proper motion is considered as a test of proximity to the earth, this result is very significant—a significance accentuated by the fact that about half the number have yielded a measurable parallax. M. Ludwig Struve found for stars of the 6th magnitude an average proper motion of eight seconds per century. As the mean distance of these stars should be—on the assumption of uniform size and brightness—ten times that of a 1st magnitude star, we should find the mean proper motion of 1st-magnitude stars to be eighty seconds in a hundred years. The twenty brightest stars in the heavens, however, show an average motion of only sixty seconds in the same time. Stars of the 2nd magnitude show a still slower motion. Instead of fifty seconds per century, due to their hypothetical distance, twenty-two stars of this magnitude yielded a mean motion of only seventeen seconds. From these results it is clear that the brightness of a star is not an absolute criterion of its distance; but, generally speaking, we may assume that the fainter stars are, on the whole, farther from the earth than the brighter ones, and that, as a general rule, faint stars have small proper motions.

How are these proper motions to be accounted for? They may be due to two causes: either a real motion in the stars themselves, or else a motion of the earth and sun through space, which would produce an apparent motion in the opposite direction. Probably, in most cases of proper motion, both causes combine to produce the observed effect. The sun's motion through space was suggested by the famous Bradley so far back as 1748. He says: "If our own solar system be conceived to Change its Place with respect to Absolute Space, this might, in Process of Time, occasion an apparent Change in the angular Distances of the fixed Stars; and in such Case, the Places of the nearest Stars being most Affected, than of those that are very remote; their relative Positions might seem to alter; tho' the Stars themselves were really immovable. And on the other hand, if our System be at Rest, and any of the stars really in Motion, this might likewise vary their apparent Positions; and the more so, the nearer they are to us, or the swifter their Motions are, or the more proper the Directions of the Motion is, to be rendered perceptible to us. Since then the Relative Places of the stars may be changed from such a Variety of Causes, considering that amazing Distance at which it is certain some of them are placed, it may require the Observations of Many Ages to determine the Laws of the apparent Changes, even of a single Star: much more difficult therefore must it be to settle the Laws relating to all the most remarkable Stars."[1]

In 1760, Tobias Mayer published the proper motion of 80 stars, and from an examination of these Mayer thought them unfavourable to the hypothesis of solar motion. Lambert, in 1761, thought it possible that all the stars, including the sun, had a motion through space, but that the sun's motion of rotation on its axis did not necessarily imply a motion of translation. Lalande, however, considered that a motion of rotation on an axis *does* necessitate a motion of translation, and this conclusion is now looked upon as highly probable, although we cannot absolutely prove it to be true.

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[1] *Philosophical Transactions* of the Royal Society, vol. xlv., for the year 1748, pp. 40, 41.

In 1783, Sir William Herschel turned his attention to the question of the sun's motion in space, and found that it was moving towards a point near the star λ Herculis. The investigations of Argelander, Peters, and O. Struve led to the following result, as stated by M. O. Struve, in his *Études d'Astronomie Stellaire*, p. 108: "Le mouvement du système solaire dans l'espace est dirigé vers un point de la voûte céleste, situé sur la ligne droite qui joint les deux étoiles, de troisième grandeur, π et μ Herculis, à un quart de la distance apparent de ces étoiles, à partir de π Herculis. La vitesse de ce mouvement est telle, que le soleil, avec tous les corps qui en dépendent, avance annuellement, dans la direction indiquée, de 1·623 fois le rayon de l'orbite terrestre, ou de 33,550,000 milles géographiques. L'erreur probable de ce dernier chiffre s'élève à 4,733,000 milles géogr., ou à un septième de la valeur trouvée. Ou peut donc parier 40,000 contre un, pour la réalité du mouvement propre progressif du soleil, et 1 contre 1 qu'il est compris entre les limites de 38 et de 29 millions de milles géographiques."

Subsequent researches on this interesting question have fully confirmed the general accuracy of this conclusion, at least so far as the *direction* of the motion is concerned. The following are some of the positions found for the solar "apex," as it is termed, or the point towards which the sun is moving. O. Struve placed the apex a little following the star ρ Herculis, and between that star and θ Herculis; Ubaghs and Airy found a point not far from Sir William Herschel's, near λ Herculis; L. de Ball between 84 and 106 Herculis Rancken and O. Stumpe, near γ Lyræ, and L. Boss a point near ϵ Lyræ, a little north following Vega Subsequent calculations by O. Stumpe place the "apex" at various points in the constellation Lyra, the position of the point found varying with the mean magnitudes, and proper motions of the stars used in the computation,[1] but as Lyra is a comparatively small constellation, the results may be considered as fairly accordant. Professor Newcomb thinks (1902) that the most probable position of the apex is in R.A. 18^h 40^m, Declination N, 35°. This is a point about 4 degrees South of Vega, and between that star and β Lyræ, a little nearer to β.

As to the actual velocity with which the sun is speeding through space, O. Struve has found, from a consideration of the proper motions of 392 stars, that the distance travelled by the sun in one year is equal to the mean distance of stars of the 1st magnitude divided by 600,000. Now, the mean parallax of stars of the 1st magnitude has been found by Dr. Elkin to be 0·089 of a second of arc, which corresponds to a distance of about 2,317,500 times the sun's distance from the earth. Hence the distance traversed by the sun in one year

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[1] *The Observatory*, November, 1896.

would be about four times the sun's distance from the earth, or about two-thirds of the earth's velocity in its orbit round the sun. Now as the latter velocity is about 18 miles per second, we have the sun's velocity in space about 12 miles a second. Following Struve's method, other astronomers have found a velocity ranging from about 6 to 30 miles a second. The discordance in these results is chiefly due to our imperfect knowledge of the distances of stars of different magnitudes.

By means of the spectroscope we can obtain a probably more accurate determination of the sun's velocity through space. As is well known, the velocity of a star in the line of sight can be found by measuring the displacement of the lines visible in the star's spectrum. Now, the stars near the position of the solar "apex" should be approaching the earth on account of the solar motion, and those at the opposite point of the sky, called the "ant-apex," should be receding. This method has been employed by several astronomers, especially by Vogel at the Potsdam Observatory. This able astronomer has found, from an examination of 40 stars, that the sun's velocity through space is about 7½ miles a second, but an examination of a larger number of stars would be necessary before we could consider this result as thoroughly established. From an examination of the spectra of 14 nebulæ, the late Professor Keeler, of the Lick Observatory, found velocities in the line of sight, and from these the French astronomer, Tisserand, has deduced a velocity of about 9⅓ miles for the solar motion, a result which does not differ very widely from that found by Vogel. More recent estimates vary from about 11·4 to 12·3 miles a second. The latter velocity would represent an annual motion of about four times the sun's distance from the earth. This agrees with O. Struve's result, and would carry the sun to the distance of Neptune's orbit in about 7½ years. To reach a star at the distance of α Centauri would take nearly 69,000 years!

An interesting question is suggested with reference to the sun's motion through space. Does this motion take place in a straight line, or in a gigantic orbit round some unknown centre? In *The Observatory* for January, 1896, Mr. G. C. Bompas considers that the various determinations of the "solar apex" show a tendency to a drift along the edge of the Milky Way, and that this drift "seems to point to a plane of motion of the sun, nearly coinciding with the plane of the Milky Way, or perhaps more nearly with the plane of that great circle of bright stars, first described by Sir William Herschel as inclined about 20° to the Galaxy, and which passes through Lyra, in or near which constellation the solar apex lies."

Recent researches seem to show that the centre of the Milky Way probably lies in a direction south of Cassiopeia's Chair and a little south of the Milky Way (about R.A. 24^h), the sun and solar system being probably situated a little to the south of the Galactic centre, and a little to the north of the plane of the Milky Way. Now, the "apex" of the solar motion lies, roughly, 90° from this point, and, judging from the position of the "apex" found by Sir William Herschel, Argelander, and Airy (about R.A. 17^h 30^m), and that indicated by recent researches (about R.A. 19^h), there may perhaps be a shift of the "apex" towards the centre of the Milky Way, which would be the case were the sun revolving round that centre. This supposed shift in the position of the "apex" may of course be more apparent than real, and may possibly be partly, or altogether, due to errors of calculation. The various positions, however, found for the "apex" show a tendency at least to shift in position towards the supposed centre of the Milky Way. However this may be, it seems not improbable that the sun may be revolving round the centre of gravity of the Milky Way, which may also be the centre of gravity of the whole system of stars composing our visible stellar universe.

The existence of dark bodies in the universe has been suspected by astronomers. Should the sun, in its journey through space, come into collision with one of these dark bodies, the result would be—were the body a large one—most disastrous to the earth. The sun's heat would be increased to an enormous extent, and, as foretold by St. Peter, "the heavens being on fire" would "be dissolved," and "the elements" would "melt with fervent heat, the earth also and the works that are therein" would "be burned up." As, however, the approaching dark body would—at a certain distance—begin to shine by reflected light from the sun, it would—if a large body like the sun—be visible for some years before the final catastrophe. It would first appear as a small star, and then becoming brighter and brighter as it approached the sun, would form a veritable "sign of the Son of man in heaven."[1]

[1] St. Matthew, chap. 24, v. 30.

VI

The Story of Gamma Virginis

THE famous binary or revolving double star, known to astronomers as Gamma (γ) Virginis, lies close to the celestial equator —about 1° to the south—and about 15° to the north-west of the bright star Spica (Alpha of the same constellation) with which and the brightest stars of the constellation Virgo, or the Virgin, it forms a **V**-shaped figure, Gamma being at the junction of the two upper branches. The brightness of γ Virginis is about that of an average star of the 3rd magnitude (2·91 Harvard). Variation of light has, however, been suspected in one or both components, and this question of light variation will be considered further on. The Persian astronomer, Al-Sufi, in his "Description of the Fixed Stars," written in the tenth century, rates the star of the 3rd magnitude, and describes it as "the third of the stars of *al-anvâ*, which is a mansion of the moon," the first and second of these "mansions" being β and η Virginis, the fourth δ, and the fifth ϵ Virginis, these five stars forming the two upper branches of the V-shaped figure referred to above. γ was called *zawiyah-al-anvâ*, "the corner of the barkers," from its position in the figure which formed the thirteenth lunar mansion of the old astrologers. It was also called *Porrima* and *Postvarta* in the old calendars. These ancient names for the stars are curious, and their origin is doubtful.

The fact that γ Virginis really consists of two stars close together seems to have been discovered by the famous astronomer Bradley in 1718. He recorded the position of the components by stating that the line joining them was then exactly parallel to the line joining the stars α and δ Virginis. This was, of course, only a rough method of measurement, and the position thus found by Bradley being probably more or less erroneous, has given much trouble to computers of the orbit described by the two stars round each other, or rather round their common centre of gravity. Bradley does not give the apparent distance between the component stars in his time, but we may conclude from the orbit—which is now well determined—that they were then nearly at their greatest possible distance apart. The pair was again measured by Cassini in 1720, by Tobias Mayer in 1756, and by Sir William Herschel in the years 1780 to 1803. These measures showed clearly that the distance was steadily diminishing, and that the "position angle" of the two stars was also decreasing. This decrease in position angle—measured from north round by east, south, and west, from 0° to 360°—shows that the apparent motion is what is called retrograde, or in the direction of the hands of a clock, direct, or "planetary motion," being in the opposite direction. The star was again measured by Sir John Herschel and South in the years 1822 to 1838, by W. Struve in the same years, and by Dawes and other observers from 1831 to the present time. The recorded measures are very numerous, and have enabled computers to determine the orbit with considerable accuracy. The rapid decrease in the distance between the components from 1780 to 1834 indicated that the apparent orbit is very elongated, and that possibly the two stars might "close up" altogether, and appear as a single star even in telescopes of considerable power. This actually occurred in the year 1836, or at least the stars were then so close together that the best telescope of those days failed to show γ Virginis as anything but a single star. Of course, it would not have been beyond the reach of the giant telescopes of our day. From the year 1836 the pair began to open out again, and at present the distance is again approaching a maximum. It can now be seen with a small telescope, and forms a fine telescopic object with an instrument of moderate power. A good telescope of 2 inches aperture should show it well.

The general character of the orbital motion may be described as follows:—In 1718, at the time of Bradley's observation, the companion star was to the north-west of the primary star. It then gradually moved towards the west and south, and in 1836, when at its minimum distance, it was to the south-east. From that date it again turned towards the north, and at present it is north-west of the primary star, and not far from the position found by Bradley in 1718.

The first to attempt a calculation of the orbit described by this remarkable pair of revolving suns was Sir John Herschel, who in the year 1831 found a period of 513 years. In 1833 he recomputed the orbit, and found a period of nearly 629 years. Both these periods were much too long, but the data then available were not sufficient for the calculation of an accurate orbit. From these results, however, Sir John Herschel predicted that "the latter end of the year 1833, or the beginning of the year 1834, will witness one of the most striking phenomena which sidereal astronomy has yet afforded, viz. the perihelion passage of one star round another, with the immense angular velocity of between 60° and 70° per annum—that is to say, of 1° in five days. As the two stars will then, however, be within a little more than half a second of each other, and as they are both large and nearly equal, none but the very finest telescopes will have any chance of showing this magnificent phenomenon. The prospect, however, of witnessing a visible measurable change in the state of an object so remote, in a time so short, may reasonably be expected to call into action the most powerful instrumental means which can be brought to bear on it." This prediction was not fulfilled until the year 1836, when the pair "closed up out of all telescopic reach," except at the Dorpat Observatory, where a magnifying power of 848 still showed an "elongation" in the apparent disc of the star.

The orbit found by Sir John Herschel was a tolerably elongated ellipse, with its longer axis lying north-east and south-west. This was not quite correct, for we now know that the axis lies north-west and south-east, and that the apparent orbit is much more elongated than Sir John Herschel at first supposed. This was soon recognized by Herschel himself, and he came to the conclusion that he and other computers had been misled by Bradley's observation in 1718. He then rejected this early and evidently rough observation, and using measures up to 1845 he found a period of about 182 years, which we now know to be not far from the truth. The orbit was also computed by the German astronomer Mädler, who found periods of 145, 157, and 169 years; by Hind, 141 years; by Henderson, 143 years; by Jacob, $133\frac{1}{2}$, $157\frac{1}{2}$, and 171 years; by Adams, 174 years; by Flammarion, 175 years; and by Admiral Smyth, who found 148 and 178 years. All these periods we now know are too small, and they show the difficulty and uncertainty of calculating a binary star orbit when the data are insufficient. Two orbits were computed by Dr. Doberck in recent years, one with a period of 180·54 years and the other 179·65 years. These orbits represent the measures well, but the period has been further extended by Dr. See, who finds a period of 194·0 years. This orbit represents recent measures closely, and seems to be very satisfactory. The angular motion is now very slow, and the star will remain an easy object for small telescopes for many years to come. The apparent orbit of the pair is a very elongated ellipse, and, as Admiral Smyth says, "more like a comet's than a planet's." The real ellipse has a very high eccentricity, nearly 0·9, indeed the highest of all known binary stars, and not much less than that of Halley's comet!

As I said above, the variability of the light of one or both components of γ Virginis has been strongly suspected. So far back as 1851 and 1852 O. Struve paid particular attention to this point. His observations in those years show that sometimes the two stars were exactly equal in brightness, and sometimes the southern star, the one generally taken as the primary star, was from 0·2 to 0·7 of a magnitude brighter than the other. There seems to be little doubt that some variation really takes place in the relative brightness of the pair. This is clearly indicated by the measures of the position angle. For example, in the year 1886 Professor Hall recorded the position angle as 154°·9, evidently measuring from the northern star as the brighter of the two, while in 1887 Schiaparelli gives 334°·2 (or about 180° more), thus indicating that he considered the southern star as the primary, or brighter of the pair. Burnham found 153°·4 in 1889, and Dr. See 332°·5 in 1891. This is also shown by earlier measures, for Dembowski found 353°·6 in 1854, and 171°·2 in 1855. The period of variation would seem to be short, for O. Struve found the southern star half a magnitude brighter than the other on April 3, 1852, while on April 29 of the same year he found them "perfectly equal." He thought that the variation was about 0·7 of a magnitude, but that the climate of Poulkova, where he observed, was not suitable for such observations. This variation is very interesting, and the question should be thoroughly investigated with a good telescope.

The distance of γ Virginis from the earth has not been directly measured, but from spectroscopic measures of motion in the line of sight, Belopolsky has recently found a parallax of 0″·051, and a combined mass equal to 15 times the mass of the sun. Taking this mass, we have the mass of each component equal to 7½ times the sun's mass. Hence, if of the same density and surface luminosity as the sun, each component would be 3·83 times brighter than the sun, and therefore both components 7·66 times brighter. Now, the sun placed at the distance indicated by Belopolsky's parallax would, I find, be reduced to the brightness of a star of 6·53 magnitude, or just below the range of naked-eye vision, and as the photometric magnitude of γ Virginis, as measured at the Harvard Observatory, is 2·91, it follows that the star is really 3·62 magnitudes, or about 28 times brighter than the sun. And as it should be only 7·66 times brighter, as shown above, it follows that the intrinsic brightness of the star is nearly four times greater than that of the sun, or else the density is less and the surface greater. Possibly both causes may combine to produce the above result. The spectrum of the star is of the type F (Pickering), that of the sun being G, so the two bodies are not exactly comparable. Stars with the F type of spectrum are probably somewhat brighter than the sun. It seems, therefore, that the mass and distance of γ Virginis, as found by Belopolsky, are probably not far from the truth.

VII

The Pleiades

THE Pleiades form perhaps the most remarkable group of stars in the heavens, and are probably familiar to most people, even to those whose knowledge of the sky is limited to a few of the brightest stars. The cluster is a very interesting and beautiful one, and forms a striking object in a clear sky. There is no other group in the heavens similar to it in the brightness and closeness of the component stars, and it seems to have attracted attention from the earliest ages. Job says, "Canst thou bind the sweet influences of the Pleiades, or loose the bonds of Orion?" And Hesiod, writing nearly 1000 years B.C., speaks of the Pleiades in words thus translated by Cooke—

> "There is a time when forty days they lie,
> And forty nights conceal'd from human eye,
> But in the course of the revolving year,
> When the swain sharps the scythe, again appear."

This passage refers to the disappearance of the group in the sun's rays in summer, and their reappearance in the evening sky in the east at harvest-time. Hesiod also speaks of them as the Seven

Virgins, daughters of Atlas and Hesperus, and in Cicero's *Aratus* they are represented as female heads, bearing the names Alcyone, Celæno, Electra, Taygeta, Asterope, and Maia, names by which they are still known to astronomers. The origin of the name Pleiades is somewhat doubtful. Some think that it is derived from the Greek word *plein*, "to sail," as their appearance before sunrise in May announced the arrival of the season for navigation. Others derive the name from the word *pleios*, "full," a name perhaps suggested by the appearance of the cluster.

Although seven stars are almost universally referred to by the ancients, Homer only speaks of six; and this is the number now visible to average eyesight. A larger number has, however, been seen with the naked eye by those gifted with exceptionally keen vision. Möstlin, a contemporary of Kepler, is said to have seen fourteen, and he actually measured and recorded the position of eleven with wonderful accuracy, without the aid of a telescope. In recent years Carrington and Denning have seen fourteen, and Miss Airy, daughter of the late Astronomer Royal, could see twelve. But to most eyes, probably only six are visible with any certainty. There is a tradition that, although seven stars were originally visible in the group, one disappeared at the taking of Troy. Professor Pickering has recently discovered that the spectrum of Pleione, which forms a wide pair with Atlas, bears a striking resemblance to that of P Cygni, the so-called "temporary star" of 1600. The similarity of the spectra suggests that Pleione may possibly, like the star in Cygnus, be subject to occasional fluctuations of light, which might perhaps account for its visibility to the naked eye in ancient times. It is a curious fact that both Ptolemy and Al-Sufi give the *positions* of only four stars in the Pleiades, and it is very difficult or impossible to identify these stars with stars in the group as they are at present. The brightest of all, Alcyone, now about 3rd magnitude, does not seem to be mentioned at all by Al-Sufi, as he says distinctly that the brightest (No. 32 of Taurus) is outside the Pleiades, "on their northern side." This 32nd star seems to have disappeared—or, at least, diminished greatly in brightness since the days of Ptolemy and Al-Sufi. More than four stars were, however, *seen* by Al-Sufi, for he adds, "It is true that the stars of the Pleiades much exceed the four mentioned, but I limit myself to these four because they are very near each other and the largest; this is why I have mentioned them, neglecting the others." It seems therefore probable that Alcyone has increased considerably in brightness since Al-Sufi observed the group in the tenth century.

The grouping of even six stars visible to the naked eye in so small a space is very remarkable.

Considering the number of stars visible in the whole sky without optical aid, Michell, writing in 1767, calculated by the mathematical theory of probabilities that the chances are 500,000 to 1 against the close arrangement of the six stars in the Pleiades being merely the result of accident. He therefore concluded "that this distribution was the result of design, or that there is reason or cause for such an assemblage." Modern observations show that his conclusion was sound. The common "proper motion" of a large number of the stars composing the Pleiades show that they are in some way physically connected.

Although to a casual observer the component stars may appear of nearly equal brightness, there is in reality a considerable difference in their relative brilliancy. Photometric measures show that Alcyone, the brightest of the group, is of the 3rd magnitude; Maia, Electra, and Atlas of the 4th; Merope, $4\frac{1}{3}$; Taygeta, $4\frac{1}{2}$; Celæno about $5\frac{1}{3}$; and Asterope about the 6th. Pleione is about $5\frac{1}{2}$, but it lies so close to Atlas that to most eyes the two will probably appear as one star. About thirty more range from the 6th to the 8th magnitude, and this is about the number visible with a good opera-glass or binocular. Galileo counted thirty-six with his small telescope, but with modern telescopes the number is largely increased. Some years ago M. Wolf published a chart showing about 600 stars, made from his own observations. Photography has further added to this number. On a photograph taken at the Paris Observatory, in 1887, with an exposure of three hours, no less than 2326 stars have been counted on a space of about 3 square degrees. The faintest stars on this photograph are supposed to be of the 17th magnitude; and as Alcyone is of the 3rd, there is a difference of 14 magnitudes between the brightest and faintest star of the group. This would seem to indicate that there must be an enormous difference in size between the components; but from photographs taken by Professor Bailey of the Pleiades and the surrounding regions, it appears that the latter are quite as rich in faint stars as the cluster itself. We may therefore conclude that many of the faint stars, apparently mixed up with the brighter stars, do not really belong to the cluster, and probably lie at a great distance behind it.

The late Mr. Webb noticed the remarkable "absence of colour" in the Pleiades, most of the stars being white, with the exception of "one minute ruby star and an orange outlier;" and this has been confirmed by other observers. Professor Pickering finds that most of the brighter components show a spectrum of the first or Sirian type, and he says, "It is very improbable that chance alone has brought together so many bright stars in the same portion of the heavens. Most of them probably had a common origin."

The brilliancy of the Pleiades cluster would naturally suggest a comparative proximity to the earth. Attempts to determine their distance have, however, hitherto proved unsuccessful. This would indicate that the distance is very great, and would, of course, lead to the conclusion that the group is of vast dimensions. An idea of the approximate distance may, however, be arrived at indirectly by a consideration of the "proper motion" of the principal stars. Professor Newcomb finds a proper motion for Alcyone of about 5·8 seconds of arc per century. This motion is in a direction nearly opposite to that of the sun's motion in space, and may possibly be due to that cause. If we assume that this proper motion is wholly due to the effect of the sun's real motion at the rate of, say, 10 miles a second, the distance of Alcyone would, I find, correspond to a "light-journey" of about 192 years. Placed at this distance, the sun would be reduced to a star of about the 9th magnitude, or 6 magnitudes fainter than Alcyone. This would imply that Alcyone is about 250 times brighter than the sun. If of the same density, its volume would therefore be nearly 4000 times the sun's volume. But as its spectrum is of the Sirian type, it cannot be properly compared with our sun.

In the year 1859 the well-known astronomer Tempel announced his discovery of a faint nebulosity extending in a southerly direction from

Merope, the nearest bright star to Alcyone. This interesting discovery was partially confirmed by other astronomers; but from its visibility to some observers with small telescopes, and the failure of others to see it with much larger instruments, the variability of its light was strongly suspected. The question remained in doubt for many years, but has now been finally set at rest by photography, which shows not only a mass of nebulous light surrounding Merope, but other nebulous spots, involving Alcyone, Maia, and Electra. Indeed, photographs taken by Dr. Isaac Roberts show that all the brighter stars of the group are more or less immersed in nebulosity, the remains, perhaps, of the nebulous matter from which the cluster has been evolved. Tennyson's simile of "tangled in a silver braid" is now shown to be a physical reality. On a photograph taken at the Paris Observatory a remarkable, narrow, nebulous ray runs nearly east and west from the Maia nebula, north of Alcyone, and apparently connects some stars of the 8th to 11th magnitude. The nebula surrounding Maia is of a somewhat spiral form, and probably represents the spiral nebula from which the star has been evolved. The existence of this nebula was not even suspected until it was revealed by photography. It was afterwards seen with the great 30-inch refractor of the Russian Observatory at Pulkowa. Were its existence unknown, however, it would probably have escaped detection, even with this large telescope, as it is one thing to see a faint object known to exist, and another to discover it independently. Maia is surrounded by several faint stars of the 12th to 14th magnitude, and the Russian observers believe that one of these is variable in light, as it was distinctly seen on February 5, 1886, when its magnitude was carefully determined with reference to the neighbouring stars; but on February 24 of the same year it could not be seen with a telescope of 15 inches aperture. Some other stars in the group have also been suspected of variation.

Photographs by Barnard, Wolf, and others show that the cluster is surrounded by patches of nebulous light, "covering at least a hundred square degrees of the sky." All the principal stars of the Pleiades show a spectrum intermediate between the "Orion" and the Sirian type, showing that they are in an early stage of their life-history, and have only recently, comparatively speaking, emerged from the nebulosity which surrounds them.

VIII

Globular Star Clusters

THE term "globular cluster" has been applied to those clusters of stars which evidently occupy a space of more or less spherical form. Some of these "balls of stars," as they have been called, are truly wonderful, and are among the most interesting objects visible in the stellar heavens. Good specimens of the class are, however, rare objects, and there are not very many in the northern hemisphere. The most remarkable is that called "the Hercules cluster," but known to astronomers as 13 Messier, it being No. 13 in the first catalogue of remarkable "nebulæ" formed by Messier, the famous discoverer of comets. It was discovered by Halley in 1714. This wonderful object lies between the stars ζ and η Herculis, nearer to the latter star. It may be seen with a binocular or good opera-glass as a hazy star of about the 6th magnitude. When examined with a good telescope, it is at once resolved into a multitude of small stars, which can be individually seen and even counted with large telescopes. The number of stars included in the cluster was estimated at 14,000 by Sir William Herschel, but the real number is probably much smaller. Were the number so great as Herschel supposed, I find that the cluster would form a much brighter object than it does. From a photograph taken in America by Mr. H. K. Palmer, with an exposure of two hours, he finds the number of stars in the cluster to be 5482, of which 1016 are "bright" and 4466 "faint." It has been also well photographed at the Paris, Harvard, and Lick Observatories, and by Dr. Roberts and Dr. W. E. Wilson. Its globular shape is evident at a glance, and we cannot doubt that the stars composing it form a gigantic system, probably isolated in space. Most people might think that this cluster was a mass of double and multiple stars, but this is not so; the components, close as they are, are too far apart to be considered as true double stars. Mr. Burnham, the famous double-star observer, finds *one* close double star near the centre, and notes the remarkable absence of close double stars in bright and apparently compressed clusters.

In the same constellation, Hercules, between the stars η and ι, but nearer the latter, will be found another object of the globular class, but not so bright or so easily resolvable into stars as the cluster described above. This is known as 92 Messier. Buffham, examining it with a 9-inch mirror, thought the component stars brighter but more compressed than in 13 Messier. A photograph by Dr. Roberts, taken in May, 1891, shows the cluster involved in nebulosity; but Professor Barnard finds that there is no trace of any real nebulosity in any of the great globular clusters when seen with the great Yerkes telescope.

Another fine globular cluster is that known as 5 Messier. It lies closely north of the 5th magnitude star 5 Serpentis. It was discovered by Kirch in 1702, and was observed in 1764 by Messier, who found he could see it with a telescope of one foot in length, but could not resolve it into stars. Sir William Herschel, with his 40-foot telescope, counted about 200 stars, but could not distinguish the stars near the central blaze. Sir John Herschel describes it as an excessively compressed cluster of a globular form, with stars of the 11th to the 15th magnitude, condensed into a blaze at the centre. Lord Rosse found it more than seven or eight minutes of arc in diameter, with a nebulous appearance in the centre. A photograph taken by Dr. Roberts in April, 1892, with a 20-inch reflector, shows the stars to the 15th magnitude. No less than 85 variable stars have been detected among the outliers of this cluster

Another fine object of this class is that known as 15 Messier, discovered by Maraldi in 1745. Sir John Herschel describes it as a remarkable globular cluster, very bright and large, and blazing in the centre, and he estimated the component stars at about the 15th magnitude. A photograph by Dr. Roberts, in November, 1899, "confirms the general description."

The cluster 3 Messier in Canes Venatici is another fine object of the globular class. Sir John Herschel describes it as a remarkable object, exceedingly bright and very large, with stars from the 11th to the 15th magnitude. Admiral Smyth thought it contained at least 1000 stars. Buffham found it resolved even in the centre with a 9-inch mirror. A photograph by Dr. Roberts, taken in May, 1891, with an exposure of two hours, confirms the general descriptions of the cluster. No less than 132 variable stars have been detected among the outliers of this cluster.

We may also mention the globular cluster known as 2 Messier, situated a little north of the star β Aquarii. It was discovered by Maraldi in 1746. Sir John Herschel compared it to a mass of luminous sand, and estimated the stars to be of the 15th magnitude. Sir William Herschel, with his 40-foot telescope, could actually "see and distinguish the stars even in the central mass." Seen as a single star, it was measured 7·6 magnitude at Harvard Observatory, and taking the component stars at 15th magnitude, I have computed that the cluster contains about 800 stars.

In the southern hemisphere there are some magnificent examples of globular clusters; and, indeed, this hemisphere seems to be richer in these objects than the northern sky. Among the southern clusters is the truly marvellous object known as ω Centauri. Its apparent size is very large—about two-thirds of the moon's diameter—and it is distinctly visible to the naked eye as a hazy star of the 4th magnitude, and I have often so seen it in the Punjab sky. It is mentioned, as a star, by the Persian astronomer Al-Sufi, who wrote a description of the heavens in the tenth century. Sir John Herschel, observing it with a large telescope at the Cape of Good Hope, describes it as "beyond all comparison the richest and largest object of its kind in the heavens. . . . All clearly resolved into stars of two sizes, viz. thirteen and fifteen . . . the larger lying in lines and ridges over the smaller; . . . the larger form rings like lace-work on it." This wonderful object has recently been photographed by Sir David Gill at the Royal Observatory, Cape of Good Hope, and also at Arequipa, Peru, by Professor Bailey, with a telescope of 13 inches aperture. On the latter photograph the individual stars can be distinctly seen and counted. The enumeration has been made by Professor and Mrs. Bailey, and a mean of their counts gives 6387; but Professor Pickering thinks that the actual number of stars contained in the cluster is about 5050, some of those counted being really outside the cluster itself.

Another wonderful object is that known as 47 Toucani, which lies near the smaller Magellanic cloud. Sir John Herschel describes it as "a most magnificent globular cluster. It fills the field with its outskirts, but within its more compressed part I can insulate a tolerably defined circular space of 90 inches diameter, wherein the compression is much more decided, and the stars seem to run together, and this part has, I think, a pale pinkish or rose colour . . . which contrasts, evidently, with the white light of the rest. The stars are equal, fourteen magnitude, immensely numerous and compressed. . . . Condensation in three stages. . . . A stupendous object." There are a number of other globular clusters of smaller size in the southern hemisphere, but the above are the most remarkable.

The actual dimensions of these globular clusters is an interesting question. Are they composed of stars comparable in size with our sun, or are the component stars really small and comparatively close together? This is a difficult question to answer, as the distance of these objects from the earth has not yet been determined. They may, on the one hand, be collections of suns similar in size to ours, and situated at a vast distance from the earth; or, on the other hand, the stars composing them may be comparatively small objects lying at a distance from the earth, not exceeding that of some stars visible to the naked eye.

Perhaps the latter hypothesis might, at first sight, be considered the more probable of the two. But really there is no reason to suppose that these swarms of suns are comparatively near our system. The probability seems to be in favour of their great distance, for in all these clusters the component stars are very faint. The question of the probable size of the component stars is one which has not hitherto been sufficiently considered. Let us examine both alternatives, and let us take the cluster ω Centauri, as one in which the number of the component stars has been *actually counted.* Assuming that the number of stars producing the light of the cluster, as seen with the naked eye, is 6387, and that they are individually equal, on an average, to our sun in size, we may estimate the distance and dimensions of the cluster. Taking the stellar magnitude of ω Centauri as 4 (as estimated at the Cordoba Observatory), I find that with the number 6387, the average magnitude of the components would be 13½. This agrees fairly well with Sir John Herschel's estimate of 13th to 15th magnitude. Now, to reduce the sun to a star of the 13½ magnitude, I find that, assuming the sun to be 27½ magnitudes brighter than an average star of the 1st magnitude, it would be necessary to remove it to a distance equal to 100 million times the sun's distance from the earth—a distance so great that light would take over 1500 years to reach us from the cluster. Taking the apparent diameter of the cluster at 20 minutes of arc, I find that its real diameter, if placed at the above distance, would be 581,760 times the sun's distance from the earth—a diameter so great that light would take over 9 years to cross it.

The distance found above for ω Centauri is certainly enormous, but judging from the average distance recently found for stars of the 1st and 2nd magnitude, the distance of stars of magnitude 13½—on the assumption that they are of the same size and brightness, and that their light is merely reduced by distance—would be about five times greater than that found above for ω Centauri. If, then, we increase the distance of the cluster five times, it will be necessary to also increase the diameters of the component stars to five times that of the sun. This would give them a volume 125 times (the cube of 5) greater than that of our sun—a result which seems highly improbable.

If, on the other hand, we do not like to admit that each of the faint points of light composing the cluster is equal in volume to our sun, let us reduce the distance five times. If we do so we must also diminish the diameters of the component stars five times. This would make them about 173,000 miles in diameter. Even this reduction of the distance to one-fifth of the value found above would still leave the cluster at an immense distance from the earth—a distance represented by over

300 years of light-travel. Portions of the Milky Way are, however, probably farther from us than this.

If we reduce the distance to one-fifth, we must also reduce the diameter of the cluster to one-fifth. This gives a diameter of 116,350 times the sun's distance from the earth. Now, assuming that the 6000 stars included in the cluster are equally distributed through the spherical space containing the cluster, I find that the distance from each star to its nearest neighbour would be over 6000 times the sun's distance from the earth.

There is, however, another point to be considered with reference to the size of the bodies composing a globular cluster. This is the character of their light. If the components of ω Centauri give a spectrum of the first or Sirian type, the above conclusions would be modified to some extent.[1] I have shown in another chapter that Sirius is much brighter than our sun would be if placed at the same distance, although the mass of Sirius is but little more than twice the sun's mass. The components of a star cluster might therefore be—if of the Sirian type of spectrum—as bright as the sun, and at the same time have a smaller mass and volume than their apparent brightness might suggest.

The most probable conclusion seems to be that

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[1] Professor Pickering finds that the majority of the stars in globular clusters have spectra of the first or Sirian type (A).

these globular clusters are composed of stars smaller than our sun in absolute size, and diminished in brightness by their great distance from the earth. They are, however, probably well within the boundary of our visible universe, and must not be looked upon as external galaxies.

IX

The Sun's Stellar Magnitude

THE stellar magnitude of the sun is the number which represents its brightness on the same scale in which the "magnitudes" or brightness of the stars are represented. In this scale the "light-ratio," as it is termed, is now generally taken at 2·512 (of which the logarithm is 0·4). This "light-ratio" denotes that a star of the 1st magnitude is 2·512 times brighter than a star of the 2nd magnitude, a star of the 2nd magnitude 2·512 times brighter than one of the 3rd magnitude, and so on.

In ancient times all the very bright stars were classed together as of the 1st magnitude, but as many of the so-called 1st magnitude stars, such as Sirius, Arcturus, Vega, Capella, etc., are considerably brighter than other 1st magnitude stars, like Aldebaran, Altair, Spica, etc., this classification is not sufficiently accurate for the requirements of modern science. These very bright stars are therefore now considered as brighter than the 1st magnitude, and their brightness is represented by a decimal fraction, the scale thus beginning from 0, or zero. But Sirius, the brightest star in the heavens, has been found by photometric measures to be brighter than the zero magnitude, and its stellar magnitude is therefore represented by a minus quantity. The Harvard measures make it –1·58, or 1·58 magnitudes brighter than "zero magnitude." Now, what figure would represent the brightness of the sun on this scale? The sun's brightness is so vastly greater than even a star like Sirius that it might be supposed that a very large number would be required to represent its brightness in the stellar scale of magnitudes. This, however, is not the case. As will be seen, the relative brightness of the stars in the assumed scale form a geometrical series, and increases very rapidly. Thus an average star of the 1st magnitude is 100 times brighter than one of the 6th, and 10,000 times brighter than a star of the 11th magnitude, and so on.

Various attempts have been made to determine the sun's stellar magnitude, but owing to its intense brilliancy, its accurate determination is a matter of no small difficulty. Comparing its light with that of the moon, Wollaston, in 1829, found it 801,072 times brighter; Bond, in 1861, found 470,000, and (by another method) 340,000; and Zöllner found 618,000. These results are rather discordant, but Zöllner's estimate is the one usually accepted as the most reliable. Wollaston found that the sun is 25·75 magnitudes brighter than Sirius; Steinheil, 23·96; Bond, 24·44, and Clark, 23·89. The arithmetical mean of these determinations is 24·51. Taking the magnitude of Sirius at −1·58, we have the sun's stellar magnitude −26·09. Professor Simon Newcomb adopts the value −26·4, and Professor C. A. Young −26·3.

As there seems to be some uncertainty as to the accuracy of this value, the following method of computing it has been suggested to me by my friend, Mr. W. H. S. Monck. Taking one of the larger planets when in "opposition," we can determine with the photometer its exact stellar magnitude. We can also compute the apparent diameter of the planet as seen from the sun, and thus ascertain the fraction representing the area of its disc compared with the area of the hemisphere illuminated by the sun. If the surface of the planet were a perfect reflector of light, we could in this way—knowing the distance of the sun and planet from the earth—compute the brightness of the sun in terms of the apparent brightness of the planet, and thus find the sun's stellar magnitude. But as no surface is a perfect reflector, a correction must be made for the "albedo" or reflecting power of the planet in question. Let us see what result this method will give in the case of Mars, Jupiter, and Saturn.

From recent measures of the diameter of Mars, I find that its apparent diameter in opposition as seen from the sun is 6″·188. This gives the area of its disc 30·0 square seconds. Now, in a hemisphere of the star sphere there are 20626·5 × 12,960,000 = 267,319,440,000 square seconds, and hence area of hemisphere is 8,910,648,000 the area of the disc of Mars as seen from the sun. Hence, if the surface of Mars were a perfect reflector, the sun as seen from Mars would be 8,910,648,000 times brighter than Mars appears to us when in opposition. But Mars is not a perfect reflector. Its "albedo" or reflecting power is, according to Zöllner, only 0·2672 (that of a perfect reflector being 1). Hence, we must divide the above number by 0·2672, which gives 33,348,233,500 for the ratio of the light of the sun to the reflected light of Mars. Now, as the mean distance of Mars from the sun is 1·5237 (that of the earth being 1), we must multiply this result by the square of 0·5237, or 0·2742, to obtain the light of the sun as seen from the earth. This gives the light of the sun 9,144,085,626 times the light of Mars when in opposition, a number which corresponds to 24·9 stellar magnitudes. Now, Professor Pickering found the stellar magnitude of Mars at mean opposition to be −2·25, that is 2¼ magnitudes brighter than a star of the zero magnitude. Hence we have the sun's stellar magnitude equal to −(24·9 + 2·25) = −27·15, a somewhat brighter value than that generally assumed.

Let us now see what value can be derived from the planet Jupiter. The mean diameter of Jupiter as seen from the sun may be taken—as the result of recent measures—at 37″·38. This gives an area of disc = 1097·4 square seconds, and a ratio of the area of the hemisphere to that of Jupiter's disc = 243,600,000. Dividing this by Jupiter's "albedo," as found by Zöllner, viz. 0·62, we obtain 392,903,100 for the ratio of the light of the sun to the reflected light of Jupiter. Now, as the mean distance of Jupiter from the sun is 5·2028 (that of the earth being 1), its distance from the earth when in opposition is 4·2028, and we must multiply the above number by the square of this, or 17·663, which gives 6,939,845,689, a number which corresponds to 24·60 stellar magnitudes. Professor Pickering finds the stellar magnitude of Jupiter in opposition to be −2·52, and adding this to −24·60 we obtain 27·12 for the sun's stellar magnitude, a result in close agreement with that found from Mars.

In the case of Saturn, we may take its mean apparent magnitude as seen from the sun at 17″. This gives an area of 226·98 square seconds, and a ratio of the area of the hemisphere to that of Saturn's disc of 1,177,722,200. Dividing this number by Saturn's albedo, 0·52, as found by Zöllner, we obtain 2,264,940,000 for the ratio of the sun's light to the reflected light of Saturn. Now, as the mean distance of Saturn from the sun is 9·5388, its distance from the earth when in opposition is 8·5388; we must multiply by the square of this, or 72·9111, which gives 165,139,266,834, a number which corresponds to 28·04 stellar magnitude. Now, it has been found by photometric measures that Saturn, when in opposition and the rings invisible, is about equal to a star of 0·88 magnitude. Hence we have the sun's stellar magnitude $= -28{\cdot}04 + 0{\cdot}88 = -27{\cdot}16$, a result in close agreement with those found from Mars and Jupiter.

From the above calculations it would seem that the sun's stellar magnitude is about −27, but as there may be some doubt with reference to the accuracy of the "albedo" assumed for each planet, this result must still be considered as open to some uncertainty. We may, however, conclude with great probability that the true value of the sun's stellar magnitude lies between −26·3 and −27·1. From some recent calculations I have made with reference to the sun's brightness compared with the brightness of binary stars having a similar spectrum, I have found from ζ Ursæ Majoris −26·34; from η Cassiopeiæ −26·65, and from α Centauri −26·70.[1] The mean of these is about −26·5, and this is the value I have adopted in the present volume.

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[1] *Monthly Notices*, Royal Astronomical Society, January, 1903.

X

The Suns of Space

THE fact that the stars are suns like our own sun has long been known to astronomers. So far back as 1750, Thomas Wright of Durham, in his work on the "Construction of the Milky Way," said, "The sun is a star, and the stars are suns;" and the poet Young, in his "Night Thoughts," says—

> "One sun by day, by night ten thousand shine."

The truth of this theory, which must have always seemed a most probable one to a thinking mind, has been fully proved in recent years by the spectroscope, which shows that the stars are incandescent bodies shining by their own light, and that many of them are almost identical in physical constitution with our own sun. All the stars, however, do not show exactly the same character of spectrum, and they have, therefore, been divided into classes or types, according to the nature of the light which they emit. Stars of the first type, like Sirius, Vega, Regulus, Altair, etc., show a spectrum with strong dark lines of hydrogen, and are believed by astronomers to be intrinsically hotter and brighter than stars with a solar spectrum, which constitute the second type of stellar spectra. The third and fourth types are essentially different from the other two, and include the red stars, many of which are variable in light. Although all the types probably represent suns of various kinds, and in various stages of their life-history, those of the second type only are strictly comparable with our sun in their physical constitution. But how are we to compare the sun with any star? The first thing necessary to know is, of course, the distance of the star from the earth, for without this knowledge the star might be of any size. It might be comparatively near the earth and of small size compared with the sun, or it might be at a great distance from us and have a large diameter. The next thing to ascertain is the relative brightness of the star compared with that of the sun. This is also most important, for the apparent brightness of any self-luminous sphere varies directly as the square of its diameter, so that if we can find the relative brightness of the sun and a star, we can compute their relative diameters, if their relative distances are known, provided that their intrinsic brilliancy of surface is the same. This latter condition we may assume to be practically true if the star's spectrum is similar to that of the sun. These two factors of distance and relative brightness being known, it becomes possible to compare directly the diameter of the sun (and hence its volume) with that of a star having the same type of spectrum. Now, it has been computed[1] that the brightness of the sun may be represented by stating that it is 26½ magnitudes above the zero of stellar magnitudes, or 27½ magnitudes brighter than an average star of the 1st magnitude, such as Aldebaran or α Crucis. The meaning of "stellar magnitude" is that a star of the 1st magnitude is 2·512 times brighter than a star of the 2nd magnitude; a star of the 2nd magnitude 2·512 times as bright as a star of the 3rd magnitude, and so on. Or, generally, if n be the difference in magnitude, then $(2{\cdot}512)^n$ will represent the difference in brightness. Hence a star of the 1st magnitude will be 100 times brighter than a star of the 6th magnitude, and the sun will be $(2{\cdot}512)^{27{\cdot}5}$ times brighter than an average star of the 1st magnitude, that is, the sun's light is equal to 100,000 million stars of the 1st magnitude.

In comparing the sun with the stars, I will first consider those stars of which the distance has been determined with some approach to accuracy, and of which the spectrum is, according to the Harvard observations, of the solar type, and therefore fairly comparable with that of the sun.

The first star I will consider is β Cassiopeiæ,

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[1] See chapter on "The Sun's Stellar Magnitude."

one of the stars forming the well-known "Chair of Cassiopeia." For this star the late Professor Pritchard found by means of photography a parallax of 0·154 of a second of arc, and Herr Kóstinsky has recently found about 0·1 of a second. This latter value would place the star at a distance of 2,062,650 times the sun's distance from the earth. Were the sun placed at this vast distance—about 32½ years' journey for light—its brightness would, I find, be reduced to that of a star of 5·07 magnitude (light varying inversely as the square of the distance). Now, the photometric magnitude of β Cassiopeiæ, as measured at Harvard, being 2·42, we have the star 2·65 magnitudes, or about 11½ times brighter than the sun would be at the same distance. Hence, if strictly comparable with the sun in physical constitution, the diameter of the star would be 3·39 ($= \sqrt{11{\cdot}5}$) times that of the sun, and its mass nearly 39 times the sun's mass. The spectrum of β Cassiopeiæ is, according to the Harvard observations, F 5 G, or intermediate between the sub-types F and G, that of the sun being G. It may therefore be slightly hotter and brighter than the sun, and its mass somewhat smaller than that found above.

For the bright star Procyon, which has the same spectrum as β Cassiopeiæ, Auwers found a parallax of 0·240 of a second, Wagner 0″·229, and Elkin 0″·325. Elkin's value would place the star at a distance of 634,660 times the sun's distance from the earth. This would reduce the sun's light to a star of 2·51 magnitude, and as the photometric magnitude of Procyon is 0·48, it follows that the star is about 6½ times brighter than the sun. This would make its diameter 2½ times that of the sun, and its volume about 16½ times the sun's volume. Dr. See finds from the orbit of the faint satellite that the mass of Procyon is about 5 times the sun's mass, so that the above result would indicate a rather hotter and brighter sun than ours, and this agrees with the star's spectrum (F Pickering).

Another star with a spectrum of nearly the solar type (F 8 G) is θ Ursæ Majoris. A small parallax of 0·046 of a second was found by Kapteyn. Placed at the distance indicated, the sun would shine as a star of only 6·75 magnitude, or invisible to the naked eye. The star's photometric magnitude being 3·22, it follows that the star is 3·71 magnitudes, or 30·48 times brighter than the sun. Its volume would therefore be about 168 times the sun's volume, so that if the parallax is at all reliable we have here a sun of large size. It has a proper motion of about 1″·1 per annum, which indicates an actual velocity of about 70 miles a second.

For the star 85 Pegasi, Brünnow found a small parallax of 0″·054. This would reduce the sun to a star of 6·6 magnitude, and as the star's photometric magnitude is 5·83, we have the star about twice the brightness of the sun. The star is a well-known binary, or revolving double star, and from an orbit recently computed by Dr. See, and the above parallax, I find that the mass of the system would be about eight times the mass of the sun. From recent measures by Comstock, he finds a combined mass of 11·3 times the sun's mass, and he arrives at the "almost incredible conclusion" that the companion star, which is only of the 11th magnitude has a greater mass than the primary star.[1] The star's spectrum is E, indicating probably a hotter and brighter sun than ours. If this be so, Brünnow's parallax is probably too large.

The southern star β Hydri of magnitude 2·90, has a spectrum of the solar type and a parallax of about 0″·13, found by Sir David Gill. This would reduce the sun to a star of 4½ magnitude. The star is therefore 1·6 magnitude, or about 4·37 times brighter than our sun, and its mass about 9 times the sun's mass. It has a large proper motion of 2″·28 per annum.

ζ Tucanæ, another southern star, has a spectrum nearly the same as that of the sun. Its photometric magnitude is 4·34, and its parallax about 0″·15. From these data I find that its mass is nearly equal to the sun's mass.

The bright stars Canopus and Procyon have spectra of the second type, that of Canopus being F, and that of Procyon F 5 G. The parallax of

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[1] *Astrophysical Journal*, April, 1903.

Procyon is about 0″·325, while that of Canopus does not exceed 0″·01, according to Gill. This would make the distance of Canopus 32 times that of Procyon. Still Canopus is a brighter star than Procyon, its photometric magnitude being, accord-to the Haward measures, −0·86, while that of Procyon is +0·48. From these data I find that Canopus is 3518 times brighter than Procyon, and it would follow that its volume is over 200,000 times the volume of Procyon. If the densities were the same the masses would be in the same ratio, and as the mass of Procyon—as found from the orbit of its satellite—is about 5 times the sun's mass, we have the mass of Canopus more than that of a million of suns! This is probably the largest sun of which we know anything.

Although stars with spectra of the Sirian type are not directly comparable with our sun in brightness, being probably much hotter and brighter, it will be interesting to consider some of the stars having this type of spectrum. In the case of Sirius itself, I find that the sun, placed at the distance indicated by a parallax of 0″·38 found by Gill, would shine as a star of 2·17 magnitude, and as the photometric magnitude of Sirius is −1·58, or 1·58 magnitudes brighter than the "zero magnitude," it follows that the star is 3·75 magnitudes, or 31·6 times brighter than the sun. Now, Dr. See finds from the orbit of the satellite that the mass of the bright star is 2·36 times the sun's mass. From this it follows that if Sirius had the same density and surface luminosity as the sun, it would be only 1·77 times brighter. Hence its intrinsic brightness is nearly 18 times greater than it would be if its physical constitution were the same as that of our sun. It would therefore seem that the great apparent brilliancy of Sirius is due to its comparative nearness to the earth combined with a great luminosity of surface, and not, as was formerly supposed, to its being a sun of enormous size. As Dr. See says, "there is reason to suppose that Sirius is very much expanded, more nearly resembling a nebula than the sun."

For the bright star Vega (α Lyræ) Dr. Elkin found a parallax of 0″·082. This would reduce the sun to 5·5 magnitude if placed at the distance of the star, and the star's magnitude being 0·14, we have the star 5·36 magnitudes, or 139 times brighter than the sun. This would make Vega a considerably larger body than Sirius, but situated at a much greater distance from the earth.

I have elsewhere considered the mass and relative brightness of those binary stars for which a parallax has been found. Let us now consider the probable distance and mass of some binary stars for which a parallax has not yet been found. The method of procedure I propose to adopt is to compute what is called the "hypothetical parallax" of the binary star, that is, its parallax on the assumption that the mass of the system is equal to the mass of the sun, and then to find the magnitude to which the sun would be reduced if removed to the distance indicated by this hypothetical parallax, assuming that the sun's stellar magnitude at its present distance is $-26\frac{1}{2}$. Comparing, then, the star's magnitude, as measured with the photometer, with the sun's reduced magnitude, it will at once appear whether the binary star is brighter or fainter than it should be if placed at the distance indicated by the "hypothetical parallax." I have computed the "hypothetical parallax" and the corresponding magnitude of the sun for all the binary stars for which an orbit has hitherto been computed, and I find that in most cases the star is brighter than the sun would be if placed at the distance indicated by the hypothetical parallax. This fact would suggest that most of the binary star systems—at least, those with spectra of the solar type—have a smaller mass than that of the sun, and are at a less distance than that indicated by the hypothetical parallax. This reasoning, of course, only applies to those binaries which have spectra of the solar type, for stars of the first type are, as already shown, much brighter than the sun in proportion to their mass.

In a valuable and interesting volume recently published by Dr. See, he gives a re-computation of the orbits of 40 of the best-known binary systems. Some of his results, all of which are based on a careful consideration of the best recorded measures, do not differ widely from those of other computers. In other cases, however, his orbits differ considerably from those previously published, and as he has included very recent measures in his discussions, his results are probably more accurate than most of those hitherto published. In the Appendix I give the period (P), and the semi-axis major (a) of the orbits found by Dr. See. From these I have computed the hypothetical parallax, or the parallax of the system, on the assumption that the mass of the system is equal to the sun's mass. To these I have added the magnitudes of the stars which have been photometrically determined at Harvard, and the character of the stars' spectrum, I. being the Sirian and II. the solar type.

Let us now consider some of the most remarkable cases in the list which have spectra of the solar type. I omit those in which the difference of magnitude between the sun and the star does not exceed 1½ magnitude, or about 4 times the light.

ξ Scorpii. Here the sun would be reduced to magnitude 6·14, giving a difference of 1·98 magnitude in favour of the star. Hence the mass of the system would be $\frac{1}{15}$ of the sun's mass. The spectrum is nearly of the solar type (F 8 G).

τ Ophiuchi. In this case the sun would be reduced to magnitude 7·48 if placed at the distance indicated by the hypothetical parallax, and the star's magnitude being 4·88, there is a difference of

2·6 magnitudes in favour of the star. Hence the mass of the system would be $\frac{1}{36}$ of the sun's mass. The spectrum is F, probably indicating a hotter and brighter star than the sun.

In the case of 99 Herculis, the sun would be reduced to 5·84 magnitude, or only 0·48 magnitude fainter than the star, and the spectrum being of the solar type, the mass of the system is probably about equal to that of the sun. The companion is very faint and of a purple colour, and it may possibly be approaching the planetary stage of its life-history.

There are two remarkable cases in which the sun, if placed at the distance indicated by the hypothetical parallax, would be considerably *brighter* than the binary star. One of these is μ_1 Herculis. Here the sun would be reduced to 4·84 magnitude, and, taking the star's magnitude at 9·4, we have a difference of about $4\frac{1}{2}$ magnitudes in favour of the *sun*. This would reduce the star's parallax to $0''\cdot013$, and would make its mass about 545 times the mass of the sun! The star being so faint, its spectrum has not been determined, but it forms a distant companion to μ_2 Herculis, the magnitude of which is 3·48 or 1·36 magnitude brighter than the sun would be if placed at the hypothetical distance. According to the Harvard observations, the brighter star has a spectrum of the type G 5 K. It does not follow, of course, that the fainter star (the binary) has a spectrum of the same type; but as both stars have a common proper motion through space, they probably lie at practically the same distance from the earth, and the only explanation of the startling result found above seems to be that the binary star has—like the companion to Sirius—cooled down, and is therefore not comparable in its physical constitution with our sun.

Another remarkable case is that of Burnham 883, a binary of very short period, whose rapidity of motion has recently been discovered by Dr. See. Here the difference of brightness is 4·24 magnitudes in favour of the sun, which would make the mass of the system about 350 times the sun's mass! But here again we do not know the character of the star's spectrum, so cannot say whether it is really comparable with the sun in brightness.

From the above results we may conclude that many of the stars are larger than our sun. On the other hand, many are probably much smaller. In fact, the visible universe probably contains suns of various sizes, a result which might reasonably be expected. That they are all, however, incandescent bodies shining by their own light is a fact which admits of no reasonable doubt.

XI

Stellar Satellites

THE term "satellite" is usually applied to the moons which revolve round the planets of the solar system, like our own moon and the satellites of Jupiter and Saturn. But the term is also sometimes used with reference to the faint companions of bright stars. In most of the known binary, or revolving double stars, the component stars which form these interesting stellar systems are usually of nearly equal brightness, or at least do not differ very much in relative brilliancy. These may be called pairs of suns, or "twin suns." There are, however, some notable exceptions to this rule. Among those for which orbits have been computed, the following are the most remarkable: Procyon, magnitudes 0·5 and 13 (or 12½ magnitudes difference in brightness); Sirius, −1·6 and 10 (about 11½ magnitudes difference); δ Cygni, 3 and 8; 99 Herculis, 6, 11; 85 Pegasi, 6, 10; and η Cassiopeiæ, 4 and 7·6. Of these double stars which are known to be binary, but in which the motion hitherto has not been sufficient to enable an orbit to be computed, the following may be mentioned: θ Ursæ Majoris, 3 and 14; α Ursæ Majoris, 2 and 11; β Leporis, 3, 11; ι Ursæ Majoris, 3, 10; η Geminorum, 3, 10; 34 Pegasi, 6, 12; and 26 Draconis, $5\frac{1}{2}$ and 11.

According to an orbit computed by Dr. See, and a parallax of $0''\cdot38$, the mean distance of the companion of Sirius from the bright star is about 21 times the sun's distance from the earth, or a little more than the distance of Uranus from the sun. The mass of the system is 3·47 times the sun's mass; the bright star being 2·36 times, and the companion 1·11 that of the sun. With the above distance I find that the companion, as seen from Sirius, would shine with about the brightness of full moonlight. As the mass of the satellite is about the same as that of our sun, its inherent light must be very small. If the sun were placed at the same distance from the earth, its light would still be more than 1300 times that of the full moon.

The bright star Procyon forms a very similar system to that of Sirius. A close companion was strongly suspected by Otto Struve in 1873, and this was discovered in November, 1896, by Schaeberle with the great 36-inch telescope of the Lick Observatory. It is about the 13th magnitude. Dr. See finds a period of about forty years, or about the same as that found by Auwers in 1861 from a consideration of some irregularities in the proper motion of Procyon. Dr. See finds the mean distance to be 21 times the sun's distance from the earth, and the mass of the satellite equal to that of the sun, or the same as in the Sirian system. The proper motion of Procyon is the same as that of Sirius—1·3 seconds of arc per annum — and its parallax—about 0″·32 — only slightly less. The similarity of the two systems of Sirius and Procyon, in almost every particular, is very curious. The spectrum of Procyon is, however, of the second or solar type, and its mass about double that of Sirius. As Sirius is considerably brighter than Procyon, we have here another proof that stars with the solar type of spectrum have a larger mass in proportion to their brilliancy than stars of the Sirian type; or, in other words, of two stars having the same mass, but one with a Sirian and the other a solar spectrum, the Sirian star would be much brighter than the solar one.

The 6th magnitude star, 85 Pegasi, has a companion of the 10th magnitude. It is a binary star, and See finds a period of 24 years, with a mean distance of 0″·89. Burnham finds 25·7 years and 0″·78. The proper motion of the system is about 1″·3, and a small parallax of 0″·054 was found by Brunnow. From these data I find that the mean distance is about 15 times the earth's distance from the sun. The orbits referred to above give the mass of the system from 4 to 8 times the sun's mass.[1] The companion as seen from the primary would shine as a small sun, so that it must be considered rather as a twin sun than a satellite. The accuracy of the small parallax is, of course, somewhat doubtful; but if nearly correct, the large proper motion would indicate a real velocity of about 70 miles a second!

In addition to the above, there are some stars which have faint companions or "satellites," the measures of which do not *directly* show orbital motion, but which are known to be physically connected from the fact that the bright star and its faint satellite have the same "common proper motion." In other words, they are moving together through space with the same velocity and in the same direction, and are therefore near enough to be bound together by the laws of gravitation. In such cases the "satellite" probably revolves round its primary, but owing to the great distance from its central sun, the period of revolution would be very long, and the angular motion would not be perceptible for many years at the great distance at which the system usually lies from the earth. Let us consider some of these stellar systems. From the comparatively great apparent distance which separates these satellites from the primary star, they seem to be constituted on a much vaster scale than those binary stars, in

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[1] Professor Comstock has, however, recently found a mass of 11·3 times the sun's mass (see last chapter).

which the motion is so rapid that an orbit can be computed. We will consider those stars for which a measurable parallax has been found, and for which, therefore, the distance from the earth is approximately known.

The bright reddish star Aldebaran has a faint companion of about the 11th magnitude at a distance of about 117 seconds of arc, which was originally discovered by Sir William Herschel. In the year 1888 this faint star was found to be a close double star by the famous American astronomer Burnham, with the 36-inch refractor of the Lick Observatory. He also found a closer and fainter companion—about the 14th magnitude—while using the 18½-inch refractor of the Chicago Observatory in the year 1877. The distance of this faint satellite from the bright star is about 31″. Measures in subsequent years have shown that the distant double companion is not moving with Aldebaran, which has a proper motion of about 0″·190 per annum; but, curious to say, Burnham's faint satellite has—notwithstanding its comparatively great distance from its primary—*exactly* the same proper motion as the bright star, and is therefore most probably physically connected with it. The result of this is that Herschel's distant companion is being gradually left behind—at least for the present—while Burnham's companion is accompanying Aldebaran in its flight through space. A parallax of 0″·107 was recently found for Aldebaran at the Yale University Observatory (U.S.A.). Assuming this parallax and the above proper motion, the velocity of Aldebaran at right angles to the line of sight comes out about 5 miles a second.[1] The double companion has a proper motion of its own in a slightly different direction, amounting to about half that of Aldebaran. As this proper motion—small as it is—is an unusually large one for so faint a star, it has been suggested by Professor Barnard that possibly its apparent motion may be really due to orbital motion round Aldebaran. However this may be—and time alone can decide the question—there can be no doubt that Burnham's faint companion is physically connected with Aldebaran, and that the double companion also forms a physical system of its own. These facts render Aldebaran and its companions an interesting object of study.

Assuming that the line joining Aldebaran and Burnham's faint companion is at right angles to the line of sight—an assumption which would give the minimum distance between them—I find that the distance of the satellite from Aldebaran is about 300 times the sun's distance from the earth. Placed at this great distance from its central sun (10 times the distance of Neptune from our sun), the period of revolution round Aldebaran

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[1] The motion *in* the line of sight seems to be much greater—about 30 miles a second away from the earth.

would be very long, and it is not a matter for surprise that no relative motion has been detected in the twenty-five years which have elapsed since its discovery. It will probably be many years more before its motion round its brilliant primary will become perceptible. Were our sun placed at the distance of Aldebaran, I find that it would be reduced in brightness to a star of about the 5th magnitude, or about 40 times fainter than Aldebaran appears to us. This indicates that Aldebaran is a more massive sun than ours, and by its greater attractive power it is able to control the motion of its distant satellite. As light varies inversely as the square of the distance, if we know the distance of Aldebaran from the earth, and the distance of the satellite from Aldebaran, we can easily compute the brightness of the satellite as seen from Aldebaran, or from some planet revolving close to the bright star. Making the necessary calculation, I find that the light of the satellite would be increased by 19 magnitudes if seen at the distance of 300 times the sun's distance from the earth. Hence, as seen from Aldebaran, the satellite would shine as a star of −5 magnitude, that is 5 magnitudes or 100 times brighter than a star of zero magnitude, like Arcturus, or somewhat brighter than Venus is seen by us at her maximum brilliancy.

A somewhat similar case is that of Regulus (α Leonis). This bright star has a companion of about 8½ magnitude at a distance of about 177″. This small attendant was discovered by Sir William Herschel in 1781. It was found to be double by Winlock, the companion being of the 13th magnitude, and distant about 3″ from the 8½ magnitude star. Burnham's measures show that this double companion is moving through space with Regulus, the common proper motion being 0″·267 per annum. A small parallax of 0″·022 was recently found for Regulus at the Yale Observatory. With these data I find that the distance of Regulus from the earth is 9,375,700 times the sun's distance from the earth, and the 8½ magnitude star is at a distance from Regulus of about 8000 times the same unit. From this it follows that the 8½ magnitude star, as seen from Regulus, would shine as a star of −6½ magnitude, or about 8 times brighter than Venus at her brightest. The 13th magnitude star would appear as a star of −2 magnitude, or somewhat brighter than Sirius as seen by us. The combination of a star 8 times brighter than Venus with one as bright as Sirius, and about one degree apart, would form a fine spectacle in the sky of Regulus. Our sun placed at the distance of Regulus would, I find, shine as a star of about 8·3 magnitude, or about the same brightness as the satellite appears to us. The satellite is therefore probably as large as our sun. The difference of about 7 magnitudes between Regulus and the sun at equal distances indicates that Regulus is over 600 times brighter than the sun. It must therefore be a very massive body, probably much larger than Sirius,[1] and may therefore be able to control the motions of a satellite even at the great distance of 8000 times the earth's distance from the sun. The parallax and proper motion of Regulus indicate that its velocity at right angles to the line of sight is about 36 miles a second.

The bright star Rigel (β Orionis) has a companion of the 8th magnitude at a distance of $9\frac{1}{2}''$, discovered by Sir William Herschel. This small star was found to be an excessively close double star by Burnham in 1871. The measures are not yet sufficient to enable an orbit to be computed, but Burnham thinks that the period of the close pair may possibly be very short. The measures of the 8th magnitude star, with reference to Rigel, do not yet indicate any well-defined motion, but as it has the same proper motion as Rigel, it is certain that there is a physical connection between them. The proper motion is small—about $0''\cdot018$ per annum. According to Sir David Gill, the parallax of Rigel does not exceed the hundredth of a second, or $0''\cdot01$. Assuming this parallax, the distance of Rigel would be at least twenty million times the sun's distance from the earth, and considering its great apparent brilliancy (0·28 magnitude), it is probably a sun of enormous size. Placed at the

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[1] Regulus has a spectrum of the Sirian type.

distance indicated by the above parallax, the sun would, I find, be reduced to a star of about the 10th magnitude! A parallax of 0″·01 would place the satellite at a distance from Rigel of 950 times the sun's distance from the earth. At this distance its magnitude, as seen from Rigel, would be about −13½, or somewhat brighter than our moon appears to us.

The 4½ magnitude star, o^2(40) Eridani, has a small companion of about the 9th magnitude at a distance of about 82″. This satellite was found to be double by Sir William Herschel in 1783. It is a binary pair, and Burnham finds a period of about 180 years. It has the same large proper motion as the bright star—about 4″·1 per annum—and a parallax, found by Hall, of 0″·22. This gives a distance from the earth of 937,570 times the sun's distance, and a distance between the bright star and its binary companion of 372 times the distance of the earth from the sun. The measures of position show evident signs of orbital motion, but the period is probably very long, perhaps several thousand years. Placed at the distance of o^2 Eridani, the sun would, I find, be reduced to a star of about 3½ magnitude, or about 1 magnitude brighter than the star. I find that the binary satellite seen from its primary would shine as a star of about −8 magnitude, or, in other words, it would give the light of a small moon. The parallax and proper motion indicate a velocity across the line of sight of about 54 miles a second.

It was suggested by Sir John Herschel, with reference to the faint companion of ι Ursæ Majoris, that it might possibly shine by light reflected from the bright star; and Admiral Smyth says, with reference to the double star Struve 946, "the possibility of the *comes* being variable awakens considerations of peculiar interest; it having been surmised that certain small acolyte stars shine by reflected light."[1] But it may be easily shown that this is highly improbable, if not impossible. Let us take the system of Sirius. In this case the satellite, although very faint for its computed mass, certainly does *not* shine by reflected light from Sirius. This will appear from the following considerations, which I have carefully worked out: Assuming for a moment that the satellite shines merely by reflected light, let us see what its brightness would be as seen from the earth. According to the computed orbit and parallax of Sirius—which are probably as reliable as those of any binary star hitherto computed—the mean distance of the satellite from the bright star is a little more than the distance of Uranus from the sun. Let us assume this distance. (A greater distance would strengthen my argument.) As the computed mass of the satellite is about the same as that of the

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[1] *Bedford Catalogue*, p. 155.

sun, let us assume that it has the same diameter, or 866,000 miles (a smaller diameter would, of course, strengthen my argument), and let us take the diameter of Uranus at 33,000 miles—which is very near the truth. Now, assuming the same "albedo," or reflective power, for Uranus and the satellite of Sirius (the albedo of Uranus is very high), we have the satellite, as seen from Sirius, shining with a greater brightness than Uranus, as seen from the sun, in the proportion of 866,000 squared to 33,000 squared, or as 688 to 1. This is on the supposition that Sirius and the sun are of the same brightness. But from the photometric measures of Sirius and its known distance from the earth, I find that Sirius is at least 20 times brighter than our sun. We must therefore increase the above ratio 20 times to obtain the illumination of the satellite by the light of Sirius. This gives 688 × 20 = 13,760. That is, the satellite as seen from Sirius would be about 13,760 times brighter than Uranus as seen from the sun. This number corresponds to 10·3 stellar magnitude. Now, taking the magnitude of Uranus as seen from the sun at 5·8 (which must be very near the truth), we have the brightness of the Sirian satellite, as seen from Sirius, equal to 5·8 – 10·3, or –4·5 magnitude, that is $4\frac{1}{2}$ magnitudes brighter than a star of zero magnitude, like Arcturus, or slightly brighter than Venus appears at her greatest brilliancy as seen from the earth. Now, the simple problem is this: If a body shines with a stellar magnitude of −4·5, as seen at the distance of Uranus, what would be its magnitude if placed at the distance of Sirius? Taking the parallax of Sirius at 0″·38, we have the distance of Sirius from the earth equal to 542,800 times the sun's distance from the earth. Hence the light of a body at the distance of Uranus would, if removed to the distance of Sirius, be reduced in the proportion of the square of 542,800 to the square of 19, or as 816,244,900 to 1. This corresponds to 22·3 stellar magnitudes. Hence the magnitude of the satellite of Sirius, as seen from the earth, *if shining only by reflected light from Sirius,* would be 22·3 − 4·5, or 17·8 magnitude, and it would be quite invisible in the great 40-inch telescope of the Yerkes Observatory. As its actual magnitude is about 10, it follows that it is about 1300 times brighter than if it shone merely by reflected light, and it is evident that it must have some inherent light of its own. I have shown in the beginning of this paper that the actual brightness of the satellite, *as seen from Sirius,* is equal to that of full moonlight on the earth. We should obtain a similar result if we assumed that Sirius is very much brighter than 20 times the brightness of the sun. If we assume it to be 10 times brighter than this, or 200 times the sun's brightness—a very improbable supposition—we should still have the satellite reduced to about the 15th magnitude, and, placed as it is so close to such a brilliant star as Sirius, it would probably still remain invisible in our largest telescopes. The assumption I have just made is, however, quite inadmissible. For if we increase the light of Sirius, we must increase its distance; and this would further diminish the computed light of the satellite. We may therefore dismiss the idea that the satellite of Sirius could possibly shine merely by reflected light from its primary. The same considerations will apply to the case of Procyon and its satellite, and with greater force, as the satellite of Procyon is about 3 magnitudes fainter that the satellite of Sirius, and Procyon is a less luminous sun than "the monarch of the skies."

XII

Spectroscopic Binaries

A NEW class of binary stars has been discovered in recent years by the aid of the spectroscope. These are called "spectroscopic binaries," to distinguish them from those binaries or revolving double stars in which the component stars are visible in a telescope. These spectroscopic binaries consist of two (or more) components so close together that the highest powers of the largest telescopes fail to show them as anything but single stars! Indeed, the velocities shown by the spectroscope indicate that, in most cases at least, they must be so close that the components will probably for ever remain invisible in the most powerful telescopes which man could ever construct. In some of these remarkable objects the doubling of the spectral lines indicates that the components are both bright bodies; but in other cases the lines are merely shifted from their normal position, not doubled, which shows that one of the components is a dark body, or at least gives so little light that its spectrum is not visible. In either case the motion in the line of sight can be measured with the spectroscope, and we can then calculate the actual dimensions of the system in miles, and thence its mass in terms of the sun's mass, although the star's distance from the earth may remain wholly unknown. Judging, however, from the apparent brightness of the star and the character of its spectrum, we can make an estimate of its probable distance from the earth.

Let us first consider the case of the famous variable star, Algol, which the spectroscope shows to be a binary star with one component a dark body, or at least very much fainter than Algol itself. The variation in the light of Algol is due to a partial eclipse by the companion. According to the Harvard observations, the spectrum is nearly similar to that of Sirius. It may, therefore, be comparable with that brilliant star in intrinsic brightness and density. Assuming the mass of Sirius to be 2·36 times the mass of the sun, as determined by Dr. See, from the orbit of its satellite, and that of the bright component of Algol at $\frac{4}{9}$ of the sun's mass, as computed by Vogel from the spectroscopic measures, I find that for the *same distance* Sirius should be about 3 times brighter than Algol. But the photometric measures of relative brightness made at Harvard show that Sirius is about 31 times brighter than Algol. From this it follows—since light varies inversely as the square of the distance—that Algol is 3·16 times farther from the earth than Sirius. Assuming the parallax of Sirius at 0″·37, as found by Sir David Gill, this would give for the parallax of Algol 0″·117, or a journey for light of about 29 years. From the dimensions of the system, as found by Vogel—about 3,269,000 miles from centre to centre of the components—this parallax would give an apparent distance of less than $\frac{1}{200}$ of a second of arc, a quantity too small to be visible in the largest telescopes, or probably in any telescope which could ever be constructed by man. It is, therefore, no matter for surprise that Burnham, the famous observer of double stars, failed to see any trace of duplicity in Algol with the highest powers of the great Lick telescope. From a consideration of irregularities in the proper motion of Algol, and in the period of its light-changes, Dr. Chandler infers the existence of a second dark body, and he finds a parallax of 0″·07. This would indicate that Algol is about 2·8 times brighter than Sirius. This greater brilliancy would suggest greater heat, and would agree with its small density, which from its diameter, as given by Vogel—1,074,100 miles—is only about one-third that of water.

Let us next consider the case of β Aurigæ, which spectroscopic observations show to be a close binary star, with a period of about 4 days, and a distance between the components of about 8 millions of miles. This period and distance imply that the mass of the system is about 5 times the sun's mass. As in this case the spectral lines are doubled at intervals, and not merely shifted from their normal position (as in the case of Algol), we may conclude that both the components are bright bodies; and we may not be far wrong in supposing that both are of equal mass, each having $2\frac{1}{2}$ times the mass of the sun.[1] As the spectrum of β Aurigæ is of the same type as Sirius, we may compare it with that star, as we did in the case of Algol, and with more confidence, as the mass of each component of β Aurigæ differs but little from the mass of Sirius. Assuming the same density and the same surface luminosity for both β Aurigæ and Sirius, I find that β Aurigæ should be about twice as bright as Sirius at equal distances. Now, according to the Harvard measures, Sirius is about 28·8 times brighter than β Aurigæ. Hence it follows that the distance of β Aurigæ from the earth should be about 7·6 times greater than that of Sirius, and assuming the parallax of Sirius at $0''\cdot37$, as before, that of β Aurigæ would be about $0''\cdot05$. From actual measures of the parallax made by Professor Pritchard at Oxford, he found from one comparison star a parallax of $0''\cdot065$, and from another star

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[1] Pickering says, "Both components are nearly equal in brightness, and have similar spectra."

0″·059, results in good agreement with that found above from a consideration of the star's mass and brightness compared with those of Sirius. We may therefore conclude with some confidence that the parallax of β Aurigæ is about $\frac{1}{20}$ of a second of arc, or a "light-journey" of about 65 years. Recent observations by M. Tickhoff, of the Poulkowa Observatory, indicate that the star is really quadruple, each of the components being itself double, and each pair revolving round their centre of gravity in a period of about 19 hours.[1] If this result is confirmed, the star will be a most interesting object—a spectroscopic quaternary!

The bright star Spica is also a spectroscopic binary. Vogel found a period of 4 days, with a distance between the components of $6\frac{1}{4}$ millions of miles. He finds that the mass of the system is about 2·6 times the mass of the sun. Assuming that each of the components has 1·3 times the sun's mass, it follows that the light of Sirius should, for equal distances, be 1·48 times the light of Spica (one of the components being nearly dark). Now, the Harvard measures make Sirius about 13 times brighter than Spica. Hence it follows that the distance of Spica should be about 3 times the distance of Sirius. This would make the parallax of Spica about 0″·12 if it had the same density and surface luminosity as

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[1] *Nature*, December 24, 1903. Tickhoff's results have, however, since been disputed by Vogel.

Sirius. But the spectrum of Spica is of the "Orion type" (B 2 A, Pickering), and it is, therefore, probably an intrinsically brighter body than Sirius. The parallax may, therefore, be smaller than that found above. So far as I know, a measurable parallax has not yet been found for Spica. Brioschi, in the years 1819–20, found a negative parallax, which would imply either that the parallax is too small to be measurable or that the small comparison stars in the vicinity, used in measuring the parallax, are actually nearer to us than the bright star. A negative parallax was also found by Sir David Gill. In addition to its orbital motion, Vogel found that Spica is approaching the earth at the rate of 9 miles a second; but, owing to its great distance, this would have no effect on its brightness in historical times.

Proceeding in the same way, I find for ζ Ursæ Majoris (Mizar), which is also a spectroscopic binary, a parallax of 0″·057. Klinkerfues found 0″·0429 to 0″·0477.

Belopolsky has found that the brighter component of the well-known double star, Castor, which has a spectrum of the Sirian type, is a spectroscopic binary with a "dark" companion, like Algol. The period is about 2·98 days, and the orbital velocity 20·7 miles a second. With these data, and assuming that the bright component has double the mass of its dark companion, and that this component of the visual pair has

4 times the mass of the visual companion (as its brightness would indicate), I find that the total mass of the system would be about 0·36 of the sun's mass. This would give a parallax of about 0″·165. From heliometer measures made in the years 1854–55, Johnson found a parallax of 0″·198, which does not differ widely from the above result.

The Pole star has also been found to be a spectroscopic double, for which Professor Campbell finds a period of $3^{d}\ 23^{h}\ 14^{m}{\cdot}3$.[1] The presence of a third component is suspected, "the visible star, with invisible companion, describing an orbit round a third body."

Another spectroscopic binary is η Pegasi, for which Professor Campbell finds a period of 818 days, with an orbital velocity of about 8·8 miles a second. The spectrum is of the solar type (G, Pickering), and the mean distance between the components about 200 millions of miles. This would indicate a minimum mass of about twice the sun's mass, and a parallax of about 0″·18.

The star η Orionis is also a spectroscopic binary, for which Walter S. Adams finds a period of 7·9876 days. The mean distance between the components is about 20 millions of miles, and "one component is relatively dark." The above data indicate a minimum mass of about 20 times the sun's mass. The orbital velocity is very great—about 89

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[1] *Astrophysical Journal*, vol. xiv. p. 2.

miles a second. The star is receding from the earth at the rate of 22 miles a second, but this may be partly due to the sun's motion in the opposite direction. η Orionis is also a visual double star, the components being of the 4th and 5th magnitude, and distant 1″, but they seem to be relatively fixed, as no motion has been detected. The brighter of the two is the spectroscopic binary. Comparing it with Spica, which has a somewhat similar spectrum, I find that η Orionis would be about 7 times farther from the earth than Spica. Its distance is therefore probably very great.

The star *o* Persei is a spectroscopic binary with a period of 4·39 days, and Vogel finds a mass equal to 0·6 of that of the sun. This is on the assumption that the plane of the orbit coincides with the line of sight. As the spectrum is the same as that of η Orionis (B 1 A, Pickering), we can compare the two stars. Supposing them to have the same density and surface luminosity, I find that η Orionis is 2·55 times farther from the earth than *o* Persei. All these "Orion type" stars seem to lie at a great distance from our system.

The bright star Capella is also a spectroscopic binary, and forms rather an astronomical enigma. It consists of two components of nearly equal mass, but one about twice as bright as the other. The period of revolution is about 104 days, and the spectroscopic observations would imply a mass of about 2·3 times that of the sun, on the assumption that the plane of the orbit is in the line of sight. But visual observations with the 28-inch refractor at Greenwich have shown the star "elongated," and indicate that the orbit plane is inclined about 60° to the line of sight. This would make the mass 8 times greater, or about 18·4 times the sun's mass. This is, however, a comparatively small mass if we consider the great brilliancy of the star. A parallax of 0″·081, found by Dr. Elkin—and this is confirmed by the Greenwich observations—would reduce the sun to a star of only 5·5 magnitude, and as the photometric magnitude of the star is 0·21, we have the star 133 times brighter than the sun. From the Greenwich observations we may assume that one of the components is about twice as bright as the other. This would make them about 89 and 44 times, respectively, brighter than the sun. Now, as the spectrum of Capella closely resembles the solar spectrum, we may perhaps assume that the surface luminosity of the components is the same as that of the sun. On this assumption I find that their diameters would be 9·4 and 6·6 times the sun's diameter, their combined volume about 1140 times the sun's volume, and their density about 0·016 that of the sun, or 0·0224 that of water. This result seems improbable, considering the character of the spectrum, and it would, perhaps, be safer to assume that their diameters are smaller and their densities greater than the results found above. On this assumption, however, their surface luminosity would necessarily be greater than that of the sun, and as greater surface luminosity would probably be indicated by a spectrum of the Sirian or "Orion" type, the enigma remains without a satisfactory solution.

One of the components of the short period binary, κ Pegasi, has been found to be a spectroscopic binary with a period of about six days, and an orbital velocity of about 25 miles a second. From these data I find a mass of 0·32 of the sun's mass, and if we suppose all three components of the system to be equal in mass, we have a total mass of 0·48 of the sun's mass. Combining this result with the elements of the orbit found for the visual pair,[1] I find a parallax of about $\frac{1}{10}$ of a second. Placed at this distance, the sun would shine as a star of about the 5th magnitude, and as the star's photometric magnitude is 4·24, it would follow that the star is somewhat brighter than the sun. This is, perhaps, indicated by its spectrum, which, according to Pickering, is F 5 G.

The star λ Andromedæ is an interesting case. This is a spectroscopic binary with a period of about 19·2 days, and an orbital velocity of about 5·6 miles a second. From this I find, supposing the orbit plane to be in the line of sight, a mass of only 0·012 of the sun's mass. As the star's spectrum is K, it is not exactly comparable with

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[1] Period = 11·42 years, and $a = 0''\!\cdot\!4216$ (See).

the sun, but as its photometric magnitude is 4·14, the very small mass would suggest that the star is comparatively near the earth. If we suppose the inclination of the orbit to be 30° (or 60° to the line of sight), the mass would be increased 8 times; but even then the mass would be less than $\frac{1}{10}$ of the sun's mass.

There are many other known spectroscopic binaries,[1] but the above are some of the most interesting cases.

It should be mentioned that in the case of β Aurigæ, Spica, Castor, and others, as there is no variation of light, as in Algol, the plane of the orbit is probably inclined to the line of sight. This would have the effect of increasing the computed mass of the system, and thus diminish the calculated parallax. As the calculations given above have been made on the assumption that the plane of the orbit passes through the earth, it follows that the computed parallaxes are a maximum, and that these remarkable objects may be really farther from the earth than even the small parallaxes found above would indicate. But as a comparatively small inclination of the orbit plane to the line of sight would prevent an eclipse, the parallaxes may not be far from the truth.

By the aid of these parallaxes we can easily compute the relative brightness of the sun compared with that of the spectroscopic binaries.

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[1] See chapter on "Some Recent Advances in Stellar Astronomy."

Assuming that the sun is 26½ magnitudes brighter than a star of zero magnitude—a value now pretty generally adopted—and taking the parallax of Algol at 0″·07, I find that the sun placed at the distance of Algol would be reduced in brightness to a star of 5·84 magnitude, or about 3½ magnitudes fainter than Algol. This implies that Algol is over 25 times brighter than the sun, although its mass is smaller. In the case of β Aurigæ, if the sun were placed at the distance indicated by a parallax of 0″·05, it would be reduced to a star of 6·57 magnitude, or 4½ magnitudes fainter than β Aurigæ, which would imply that the star is about 63 times brighter than the sun! In the case of Castor we have the sun reduced to about the 4th magnitude, and as the photometric magnitude of Castor is 1·58, the star would be over 9 times brighter than the sun, although its mass is considerably less. These results show the great relative brilliancy of stars with a Sirian type of spectrum when compared with that of the sun, a conclusion which has been already arrived at from other considerations.

The "spectroscopic binaries" are probably very numerous. Professor Campbell estimates that one star in every five or six is a spectroscopic binary, and that, if so, there should be at least 800 Algol variables brighter than the 9th magnitude. At present the number of known variables of this type is not much over 30. Professor H. N. Russell and Dr. A. W. Roberts have shown, independently, that the density of the Algol variables (and therefore presumably other spectroscopic binaries) is very small. Professor Russell finds the mean density of 17 Algol variables to be only 0·19 that of water, and Dr. Roberts finds a mean density of 0·187 for 4 southern Algol variables.[1] This would suggest that these systems are in an early stage of their evolutional history, and this evidence is strengthened by the character of their spectra, which are all of the "Orion" or Sirian type.

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[1] *Astrophysical Journal*, vol. x. p. 314.

XIII

"The Darkness behind the Stars"

THOSE who have not given the matter sufficient consideration seem to think that the number of the stars is practically infinite. But this idea is quite erroneous, and due to complete ignorance of astronomical investigations. The number of stars visible to the naked eye, even with very good eyesight, is not only comparatively but *absolutely* small, not much exceeding 7000 for the *whole* heavens, and probably double this number would exhaust those which can be seen by persons gifted with exceptionally keen vision. An attempt to count those seen with *certainty* in any selected portion of the sky will convince any intelligent person that the number visible to ordinary eyesight, instead of being large, is really very small, and that the idea of a countless multitude is simply a popular fallacy based on an optical illusion.

Of course, the number of stars visible is largely increased when we use a telescope—even a small one—and it is true that the larger the telescope the more the number of stars seems to increase. But we now know that there is a limit to this increase of telescopic vision, and that the number of stars visible even in the largest telescopes, or disclosed by photography, is certainly limited. Let us consider some of the evidence derived from telescopic observation which leads to this conclusion. In the *Philosophical Transactions* of the Royal Society for the year 1784, Sir William Herschel says that from his "gauges" of stars in the Milky Way near Orion with a reflecting telescope of 18·7 inches aperture, he found an average of 79 stars for each field of view of 15 minutes of arc. From this he concludes that "a belt of 15 degrees long and 2 broad" would contain about 50,000 stars, and he "suspected at least twice as many more," or a total of 150,000 stars on an area of 30 square degrees. Taking the smaller number, we have about 1700 stars to the square degree. This would give for the whole sky—which contains 41,253 square degrees—a total of 69 millions; and if we take the larger estimate, we have a total of about 207 millions. But this counting of stars was made in the Milky Way, which is, of course, exceptionally rich in stars, and cannot therefore be taken as representing the whole heavens. In a recent investigation on star distribution, Professor Pickering, of the Harvard Observatory, finds that the richer portions of the Milky Way cover 10,999 square degrees, and the fainter parts 4613 square degrees, leaving 25,641 square degrees in which there is no Milky Way light.[1] Now, if we take the richer parts as containing 5000 stars to the square degree, the fainter parts 2000 to the square degree, and the rest of the sky at 1000 stars to the square degree, we obtain a total of about 64 millions in the Milky Way and 26 millions outside, or a grand total of 90 millions for the whole sky. Professor Pickering says, "As estimates are frequently given which are still more uncertain . . . it may be stated that the number of stars corresponding to the magnitude 15, or which would be visible in a telescope of 15 inches aperture, would be about 18 millions, and the increase for larger apertures would be surprisingly small."

Let us now consider some other results of modern observations and photographs. And let us first take an *exceptional* case of stellar richness. On a photograph of the great globular cluster ω Centauri, taken in Peru by Professor Bailey, with a telescope of 13 inches aperture, the individual stars can be distinctly seen and counted, although to the eye it seems to be a mass of "innumerable" stars. The enumeration has been carefully made by Professor and Mrs. Bailey, and gives a total of about 6389 on an area of about 30 minutes square. This gives 25,556 stars to the square degree, and a total of about 1054 millions

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[1] *Annals of Harvard College Observatory*, vol. xlviii. No. V.

for the whole sky. But clusters like ω Centauri are of course remarkable, and rare exceptions to the general rule of stellar distribution, and the heavens as a whole are not—even in the very richest portions of the Milky Way—nearly so rich in stars as the globular clusters. The fact of these clusters being "remarkable" objects proves that they are unusually rich in stars, and there is strong evidence—evidence amounting to absolute proof—that the stars in these clusters are really and not apparently close, and that they are actually systems of stars which fill a comparatively limited volume in space. We cannot, then, estimate the probable number of the visible stars by counting those visible in one of the globular clusters. We must therefore draw our conclusions from other portions of the sky.

On a photograph of a rich spot in Cygnus, taken by Dr. Isaac Roberts in September, 1898, in that luminous region of the Milky Way between γ and β Cygni, about 30,000 stars have been counted on a space of about $3\frac{1}{2}$ square degrees. This would give a total of about 360 millions for the whole sky. But as the region in question is a very rich one, this number is evidently too large. On this beautiful photograph the stars, although thickly strewn, have numerous and comparatively large black spaces between them, and "the dark background of the heavens" is very conspicuous even in this "rich" region. A glance at the photograph shows that there would be ample room, and to spare, for at least ten times the number of stars actually visible. With reference to this photograph, Dr. Roberts says—

> "A photograph of this region was also taken on the 17th August, 1895, with an exposure of sixty minutes only, and on comparing the original negative with that of the plate annexed, all the star-images, down to the faintest, are found to be visible on both, notwithstanding the fact that one had sixty minutes' exposure and the other two hours and thirty-five minutes. The sensitiveness of the films and the quality of the sky during both exposures may be considered equal, and the only noticeable difference in the star-images on the two negatives is greater density on that with the longer exposure. This is an illustration (one of several which could be adduced) pointing to the probability that all the stars existent upon this area of the sky are charted upon these negatives. Of course the faintest star-images are lost on the photo-enlargement on paper. The inferences we may draw from these results are that this, apparently one of the most densely crowded star areas in the *Milky Way*, can be seen through, and that nothing visible within the limit of our powers lies beyond; and, further, that the limit in space of the *Galactic System* is now probably revealed to us."

In comparison with the exceptionally rich region considered above, there are many poor regions in the sky in which the visible stars are comparatively few in number. A photograph taken by Dr. Roberts near the pole of the Milky Way showed only 178 stars to the square degree. This would give a total of only 7,343,000 stars for the whole sky!

With reference to a photograph of the cluster Messier 35, and the small cluster near it, Dr. Roberts says—[1]

> "Both the clusters and the stars surrounding them present to view in a striking manner numerous curves and lines of stars with void spaces between them, which enable us to view the darkness of space beyond the *Galactic* stellar universe, of which the solar system forms a relatively insignificant point. Many astronomers have tacitly adopted the assumption that the stars extend indefinitely into the expanse of space, but that the reason they cannot be seen is the absence of sufficient telescopic power to reveal the very feeble light of stars that are beyond the range-limit of all existing telescopes. But the evidence obtained by the aid of photography during the past twelve years strongly indicates, if it does not demonstrate, that those vacant spaces which are visible on photographs that have been exposed to the sky during intervals of seven to twelve hours are really void of stars. This inference is based upon the fact that photographs have been taken of identically the same areas in the sky, but with exposures of only ninety minutes show the same stars, including those of the faintest magnitudes, that were shown on the plates exposed up to twelve hours. Therefore we are justified (by our present knowledge) in adopting the inference that no fainter stars exist, and that the universe which includes all the stars and the nebulosity of the Milky Way is limited in extent, and that it may be considered as a separate and

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[1] *Knowledge*, January, 1901.

distinct aggregation of stars and of material of which stars are made, independently of other similar stellar aggregations which may exist in the inconceivable expanse of space beyond the *Milky Way.* This view, based as it is on credible evidence, would reduce the whole of the solar system, including the planets and satellites, to a mere speck relatively with the Galactic universe alone, and relatively with the others that may be beyond, inconceivably small—a microscopic speck. What, then, about the earth, which we naturally look upon as a world of great importance? Important, of course, it is to the million forms of life that exist upon it, ranging between the monad and the elephant, or the whale, or man, but very small relatively with the solar system, and insignificant relatively with the Galactic universe."

I quote this long extract to show that my views respecting the limited number of the visible stars, and which I have maintained for many years, are supported by those of the greatest living authority on astronomical photography.

Taking into consideration the rich and poor regions of the heavens, it is now generally admitted by astronomers who have studied this particular question—and who alone are qualified to express an opinion on the subject—that the total number of stars visible in our largest telescopes does not probably exceed 100 millions—a number which, large as it *absolutely* is, is *comparatively* small when compared with even the human population of the earth—estimated at 1500 millions—

PHOTOGRAPH OF THE MILKY WAY NEAR MESSIER 11.

By E. E. Barnard, Lick Observatory.

and may be considered as a vanishing quantity when compared with an infinite number.

Taking this total number of 100 millions, and supposing the stars equally distributed over the whole sky—which, of course, they are not—I find that the apparent distance between them would be about 73 seconds of arc, so that the stars would be widely separated even in a small telescope. For Dr. Roberts' photograph in Cygnus the distance would be about 38 seconds, and even for the closely "compressed" cluster ω Centauri the distance between the stars would be 22 seconds.

In some remarkable photographs of the Milky Way in Sagittarius and Aquila, taken by Professor Barnard at the Lick Observatory, there are, in addition to clouds of small stars and apparent nebulosity, numerous dark spots and "lanes" which seem quite black in comparison with the luminous portions adjoining them. These photographs give us the impression that we are looking through a comparatively thin stratum of stars, that is, thin in comparison with its distance from the earth.

The fact of the visible stars being limited in number seems to show beyond a doubt that we live in a limited universe, which is isolated by a dark and starless void from any other universes which may exist in the infinity of space beyond.

XIV

The Nebular Hypothesis

THE origin of the solar system has always formed a subject of interest to the human mind from the earliest ages to the present time. The question which naturally suggests itself is, whether the system was originally created in its present form, or whether it has been evolved and developed in the course of ages from some pre-existent form of matter. The account of the creation of the world given in the first chapter of the Book of Genesis throws no light on the point at issue. The opening words of that remarkable and graphic narrative are, "In the beginning God created the heaven and the earth. And the earth was without form, and void." This clearly refers to the state of the earth before the appearance of life on its surface, but gives us no information with reference to its condition previous to that epoch, except that it was "without form, and void." With exception of the sun and moon, no other members of the solar system are referred to. The account, therefore, leaves it an open question as to how the system acquired its present form and constitution, and we seem justified in considering any theory admissible, or at least provisionally acceptable, which will explain satisfactorily in what manner the sun, planets, and satellites which compose the solar system came to exist in their present relative positions. Of course, on the theory of creation by the direct will of the Almighty, we might assume at once that the system was created as it stands (or rather moves); but such a theory is highly improbable, and in view of recent discoveries, a hypothesis of this kind would be repugnant to the scientific mind, and indeed, we might say, opposed to observed facts.

The nebular hypothesis of the origin of the solar system has been supposed by some shallow-minded and ignorant people to be in opposition to revealed religion. But this is not the case. On the contrary, such a hypothesis should tend to exalt our ideas of the great Creator. As Herbert Spencer has well said, "Creation by manufacture is a much lower thing than creation by evolution. A man can put together a machine; but he cannot make a machine develop itself." This is evidently true, and the hypothesis of evolution from matter previously created should increase our wonder and admiration for the power of the Almighty Creator.

The hypothesis of the formation of the solar system from a mass of gaseous matter—usually ascribed to the famous French mathematician Laplace—seems to have been first suggested by the great German philosopher Immanuel Kant. In the year 1755 this great thinker published a work on the construction of the heavens, in the second part of which he deals with the origin of the solar system, and suggests that it might have been formed by the condensation of gaseous matter scattered through space. He supposed that these scattered portions of gas were drawn together by the force of gravitation, and that, slowly consolidating, they eventually became solid bodies, which now form the sun and planets. But his views are sometimes rather vague and unsatisfactory, and lack the unity we find in Laplace's hypothesis. To Kant, however, seems certainly due the credit of having first advanced the bold hypothesis of the evolution of worlds from a primitive mass of gas. But his primitive mass differs essentially from Laplace's nebula, both in its properties and in the character of its motion, and his views are frequently in direct opposition to those of Laplace. In dealing, therefore, with the nebular hypothesis, we will only consider the views propounded by Laplace with reference to this remarkable and interesting theory.

Laplace's hypothesis was first published towards the close of the eighteenth century, in a work entitled "Exposition du Système du Monde." In putting it forward he says, "I present this hypothesis with the distrust which everything ought to inspire that is not the result of observation and calculation."

The fundamental idea of Laplace's hypothesis is very simple and easily understood. He supposed that the matter which now forms the sun, planets, and satellites originally existed in the state of gas, and that this gaseous mass formed a vast globe, which extended from the sun's present position as a centre out to, and perhaps beyond, the orbit of Neptune.[1] Laplace does not attempt to explain how this gaseous mass originated. He merely assumed its existence, and uses it as a starting-point from which the solar system was eventually evolved by condensation and solidification. We might conjecture that this enormous mass of gas of nearly globular shape was possibly formed by the collision of two dark bodies in space, but at present we will assume, as Laplace did, that the gaseous mass existed, and examine the consequences which will follow. To suit his hypothesis, Laplace was obliged to make another assumption, and this was that the gaseous mass was endowed with a motion of rotation on itself,

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[1] Laplace's words are: "L'atmosphere du Soleil s'est primitivement étendue au dela des orbes de toutes les planètes, et qu'elle s'est reservée successivement jusqu'a ses limites actuelles." The existence of Neptune was, of course, unknown to Laplace.

in the same way that the earth rotates on its axis. This assumption was clearly necessary, for if we suppose the gaseous mass to have had no rotation, it would, when its particles began to fall towards the centre, eventually consolidate into a *single body* or sun, without planets or satellites. To account, therefore, for the existence of planets and satellites in the solar system, we must suppose that the original gaseous globe had a motion of rotation on an axis. For what will be the result of such a rotation? Rotating and revolving bodies develop what is called centrifugal force. A stone whirled round in a sling is an example. The stone constantly tends to escape from the sling by the centrifugal force produced by the rapid revolution of the stone round the head. A similar tendency is produced in any rotating body. The fly-wheel of a steam engine is an example. It exists on the earth's surface, but is restrained by the force of the earth's attraction. If the earth rotated 17 times faster than it does (or in 1 hour 25 minutes), bodies at the equator would have no weight. The attraction of the earth would just be counterbalanced by the centrifugal force. With a slightly more rapid velocity of rotation they would be shot into space, never to return. That is, of course, loose bodies lying on its surface. The solid rock would not, of course, move, as the force of cohesion would prevent it from being disturbed. In the gaseous mass supposed by Laplace the power of cohesion would be, of course, very weak, so that a slight motion of rotation would be sufficient to detach portions from its surface. The tenuity of such a mass is almost inconceivable. It has been computed that if the total mass of matter contained in the solar system were reduced to a gas of such rarity that it would fill a sphere of a diameter equal to that of the orbit of Neptune, its density would be over 16 million times less than that of hydrogen gas!

It may be easily imagined that the force of cohesion in such an attenuated gas would be very small indeed, and that a very small motion of rotation would be necessary to produce disruption at the external surface. Further, the gaseous mass would soon begin to consolidate, owing to the gravitation of its particles towards the centre of the sphere, and this condensation and reduction of volume would—according to a well-known law—increase the velocity of rotation. A point would then be reached when, according to Laplace's hypothesis, some of the gaseous matter would be detached from the parent mass in the form of a ring. This ring would probably break up into separate globular masses, and if one of these masses was very much larger than the others, it would gradually gather them in by the force of its attraction, and eventually form a spherical gaseous mass, which would afterwards consolidate into a planet revolving in an orbit round the original mass. Before consolidating, however, these smaller masses might, in their turn, detach rings, which would subsequently form satellites revolving round the planet. The parent mass would go on condensing and throwing off rings, one for each planet, until at last it had consolidated into a central nucleus, forming the sun as we see it now.

Such is an outline of Laplace's famous nebular hypothesis, which has been attacked and defended for nearly a hundred years, and which still forms a subject of discussion among astronomers and physicists.

Laplace's hypothesis satisfactorily explains the following facts connected with the solar system: (1) the approximate coincidence of the planetary orbits with the plane of the sun's equator; (2) the small eccentricity of the orbits, which originally were probably circular; (3) the direction of revolution of the planets round the sun, and their rotation on their axes; also the motion of the satellites round their primaries—all in the same direction (with exception of the satellites of Uranus and Neptune). This accordance in the motions is very remarkable, and the probability against such an arrangement being the result of mere chance is enormous. Indeed, the agreement of the above facts with Laplace's hypothesis has always been justly considered as strong evidence in its favour. When Laplace's views were published, only five small planets were known between Mars and Jupiter. The number of these small bodies has now risen to over 500, and they all revolve round the sun in the same direction as the other planets, a fact which further strengthens the hypothesis. The theory has, however, been assailed by numerous writers, and the following are some of the principal objections which have been advanced against it.

1. The objection has been raised that in a nebulous mass of such tenuity as the original nebula must have had, the formation of rings would be impossible. But those who advanced this objection seem to have overlooked the fact that Laplace supposed that, previous to the formation of the rings, a nucleus had been formed of considerably greater density, and that the rings were separated from this nucleus, and not from a homogeneous mass of gas. This nucleus had probably a very flattened, disc-like shape.

2. Admitting the formation of rings from the parent mass of gas, it has been argued that the formation of planets by condensation of these rings would be impossible. But M. Roche has shown that the formation of planets from rings of nebulous matter *would* be possible under certain conditions.[1]

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[1] Professor Stockwell has, however, recently shown that the rings would *not* consolidate (*Astronomical Journal*, No. 557).

3. Another objection which has been raised against the nebular hypothesis is that many of the satellites are at distances from their primary which are inconsistent with Laplace's theory. The moon is a case in point. Its distance from the earth is greater than the radius which the earth in its gaseous state would probably have had at the time of the moon's formation from a nebulous ring. The inner satellite of Mars, Phobos, forms an exception in the opposite direction, its period of revolution being less than the planet's period of rotation on its axis. This point was briefly considered by Laplace with reference to the satellites of Jupiter. A more careful investigation of the subject has, however, been undertaken by M. Roche. He considers that the satellites were not formed during the early existence of the planetary nebula, and would not be formed until the nebula had—like the original solar nebula—considerably condensed at the centre, the mass being influenced in this case also by strong tidal solar action. It follows from M. Roche's investigations that the planets nearest to the sun, being acted on by a stronger tide, would produce satellites more slowly and at a smaller distance from their primary. The moon, being an exception to this rule, must have been formed under peculiar conditions. The moon's comparatively great distance of 60 times the earth's radius is considered as an objection to Laplace's

hypothesis. Calculation shows that when the gaseous mass, which afterwards consolidated and formed the earth, rotated in a period of 27·3 days (the moon's period of revolution), the nebulous mass would have extended to only three-fourths of the distance which now separates the moon from the earth. M. Roche, however, points out that in considering the effects of tidal action on the nebulous mass, we should—as in the case of oceanic tides on the earth—take into account, not the absolute attraction of the sun, but the difference between the solar attraction exercised on a molecule of the atmosphere and that exerted on the centre of the earth. On this view of the matter he finds that the longer axis of the nebulous spheroid would, at the epoch referred to, be exactly 60 radii of the earth as it exists at present. This axis would, however, be always directed towards the sun, the other axis at right angles to the major axis being shorter. M. Roche then concludes that the moon had its origin, not in a ring, but in matter thrown off at the extremity of the longer axis at a time when the nucleus had sufficiently consolidated. Researches by M. Simon agree with those of M. Roche. The formation of internal rings in the nebulous mass which afterwards formed the planet Mars would account, on this hypothesis, for the formation of Phobos, which seems to have been of relatively recent origin compared with the age of our moon.

4. Another objection to the nebular hypothesis is that the satellites of Uranus and Neptune revolve round these planets in a retrograde direction. The question of the rotation of these planets on their axes has not yet been finally decided, but it seems highly probable from analogy that they rotate in the same direction as the satellites revolve round their primary. It seems probable, according to the nebular hypothesis, that the planets, when first formed, had their axes of rotation at right angles to the planes of their orbits, or the general plane of rotation of the original nebula. How, then, was the axis of Uranus brought so nearly into coincidence with the plane of the planet's orbit? The answer to this question would involve the general one, Why are the equators of all the planets more or less inclined to their orbit planes? As far as is accurately known, the planet Jupiter is the only one whose equator plane nearly coincides with the plane of the orbit, the angle between the two being about 3 degrees. This question has been considered by Professor G. H. Darwin and M. Simon. The latter has shown that if we suppose the earth to have been formed by the consolidation of a series of rings, the inclination of these rings, acted on by the attraction of the sun or central nucleus, would have increased in time. Professor Darwin, supposing the planet to be in the state of a viscous spheroid—which, according to Lord Kelvin, is

subject to the same laws as a nebulous mass—concludes that every increase in the equatorial protuberance would tend to increase the inclination of the equator to the plane of the planet's orbit. In the case of the more distant planets he is obliged to invoke the aid of the satellites.

M. Wolf, reviewing all the objections which have been raised against the nebular hypothesis, considers that most of them have been satisfactorily answered. He thinks that only two doubtful points remain: (1) how the gaseous matter of the ring left behind by the original nebulous mass was consolidated into a planet of large size; and (2) how the inclinations of the planetary equators and the orbits of the satellites on the planes of the planets' orbits have been produced. These difficulties are, however, not peculiar to Laplace's views, but are common to all theories which suppose the planetary system to have been evolved from a rotating nebulous mass.

Let us now consider the evidence which modern discoveries afford in support of the nebular hypothesis. The existence of spiral nebulæ was unknown to Laplace. Had he known them he would probably have considerably modified his theory, and we should probably have heard less of ring formation in nebulous masses. These wonderful objects were discovered by Lord Rosse about the middle of the nineteenth century, and his discovery—at one time doubted—has been fully confirmed by photographs taken by Dr. Isaac Roberts and others. The Crossley reflector at the Lick Observatory (U.S.A.) has revealed by photography thousands of new nebulæ, and the late Professor Keeler estimated that it would show in the whole sky at least 120,000 nebulæ. Of these he considered that at least one-half would be spiral. According to Scheiner, the spectra of spiral nebulæ are generally continuous; in other words, "a spiral nebula is not gaseous." They have probably sufficiently condensed from their original gaseous state, and formed liquid or solid particles. These would give a continuous spectrum. He finds that the spectrum of the great nebula in Andromeda—which Dr. Roberts finds to be spiral—shows no trace of bright lines (as gaseous nebula show), and he considers that the component particles, although too small to be visible in the largest telescopes, may still constitute small stars. The spectrum is somewhat similar to that of the sun. Dr. Roberts' photographs show that the spiral nebulæ, when seen edgewise, are comparatively thin in proportion to their diameter, and approximate to a disc-like form. This tendency to formation in a plane is also shown by the solar system, the rings of Saturn, and even by the Milky Way. It may be shown by the principles of dynamics that this tendency to motion in a plane is due to a law known as "the conservation of the moment of momentum." The original amount of energy with which the system was endowed may be slowly dissipated by conversion of motion into heat, and radiation of this heat into space, but the moment of momentum must be preserved, and it may be shown that motion in a plane fulfils this requirement with the minimum amount of energy.

The great nebula in Orion, and other similar gaseous nebulæ, probably represent the original form from which spiral nebulæ are evolved. The transformation is probably caused by loss of energy and reduction of volume. The diminution of volume would, of course, produce consolidation, and hence the fact is explained that spiral nebulæ show a continuous spectrum, indicating that the original gaseous mass has partially condensed, and will eventually, in the course of ages, assume the solid form. The spiral nebulæ—at least the larger members of the class—are, of course, on a much vaster scale than our solar system. They probably represent stellar systems and globular clusters in process of formation. It is probable, however, that the solar system was formed from a small spiral nebula.

These recent discoveries seem to show that it is now necessary to modify Laplace's original hypothesis to a considerable extent. Instead of the formation of the solar system from a globe of gaseous matter, we must now assume that the sun, planets, and satellites were evolved from a spiral nebula by portions of partially condensed nebulous matter being detached, or left behind, in the form of *masses*, and not in the shape of *rings*, as Laplace supposed. This gets rid of the difficulty of explaining the condensation of the rings into planets which has always been one of the chief objections to Laplace's hypothesis.

Other objections are also satisfactorily met by modern discoveries, and we may say that the nebular hypothesis of the evolution of the solar system from a gaseous mass now stands on a firmer foundation than it ever did before. In the great spiral nebula in Canes Venatici (Messier 51), in the great nebula in Andromeda, and in other beautiful and perfect specimens of the spiral nebulæ, we seem to see stellar and solar systems in the actual process of formation before our eyes.

The phenomena of "new" or "temporary" stars, which, in most cases—like the recent new star in Perseus—have turned into gaseous nebulæ, seem to suggest that the original nebula from which suns and systems are formed may possibly have been produced by the collision of two dark bodies in space, as suggested by the late Dr. Croll, a collision which would have the effect of converting the solid bodies into the gaseous state by the transformation of motion into heat. As no "moment of momentum" could be produced by a perfectly *direct* collision, it was probably

THE SPIRAL NEBULA, 51 MESSIER.

From a Photograph by W. E. Wilson, F.R.S.

a "grazing" one. This would give rise to a motion of rotation in the gaseous mass, a motion which still survives in the revolutions of the planets and satellites and the rotations on their axis.

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XV

Stellar Evolution

ACCORDING to the nebular hypothesis of Kant and Laplace, the sun and solar system were in the course of ages gradually evolved by condensation from a primitive mass of nebulous matter. To account for the existence of this original nebula, the late Dr. Croll, the well-known geologist, imagined the nebulous mass to have been formed by the collision of two dark bodies in space, a collision which would have had the effect of converting the solid bodies into the gaseous state, owing to the heat produced by the collision. This hypothesis would evidently be applicable to all the stars as well as to the sun, which is merely the nearest of the stars to the earth; and whether *all* nebulæ had their origin in such collisions or not, it seems probable that we now see in the heavens many nebulæ which are evidently going through the process of conversion into suns and planets. The wonderful spiral nebulæ, which have been disclosed in recent years by telescopic and photographic research, suggest strongly the idea that we see before our eyes the evolution of nebulous matter into suns and planets. Laplace's nebular hypothesis supposed that the planets were formed from the original solar nebula by the condensation of *rings* detached from the parent mass by the force of the rotation, a rotation for which Laplace assigned no reason, but which, on Croll's hypothesis, might be accounted for by supposing the dark bodies to have collided, not in a direct line, but in an oblique or "grazing" collision. However this may be, the spiral nebulæ are evidently endowed with rotation. Their aspect clearly implies this, and the photographs of these wonderful objects show that the portions in process of formation into stars or planets are detached from the parent nebula, not in the form of rings, but in separate *masses*. And this process seems much easier to understand, and appears much more probable than the separation of rings supposed by Laplace. The hypothesis of ring formation was probably suggested by the existence of Saturn's rings. But in this case the formation of a ring was probably due to an abortive attempt at the formation of a planet too close to Saturn's globe. According to Roche's law, a satellite could not have been formed in this position, as it would have been torn to pieces by tidal action. This has actually happened in Saturn's rings, which are composed of a multitude of small bodies.

Photographs of the great nebula in Andromeda seemed at first sight to show a good example of ring formation in a nebulous mass. But Dr. Roberts' photographs now show that this wonderful object is not annular but spiral, and even in the annular nebula in Lyra, Schaeberle finds evidence of a spiral structure. As there was always considerable difficulty in explaining satisfactorily how Laplace's rings could have consolidated into planets, the evidence derived from the spiral nebulæ should tend to simplify the nebular hypothesis, and make it, in its general form, more acceptable and probable.

From an inquiry into the structure of nebulæ, the late Professor Keeler found that spiral nebulæ are much more numerous in the heavens than was formerly supposed, and that "any small, compact nebula not showing evidence of spiral structure appears exceptional." Even Herschel's "spindle-shaped nebulæ" probably belongs to the spiral class.

These marvellous creations are more magnificent and sublime objects than all the art that Ruskin wrote of. One is the work of the Almighty Architect, the other the feeble efforts of weak and fallible man.

From the probably great distance of these spiral nebulæ from the earth, and their comparatively large apparent size, we may conclude that they are in reality of vast dimensions. The apparent diameter of some of them shows that they must be much larger than our solar system. Seen from the nearest fixed star—α Centauri—the diameter of the solar system would subtend an angle of about 45 seconds of arc, while the apparent diameter of the spiral nebula in Canes Venatici (51 Messier) and that of 74 Messier is about 300 seconds, and these nebulæ are probably much farther from the earth than α Centauri. The great nebula in Andromeda is of still larger dimensions. What the origin of spiral nebulæ was we do not, of course, know; but possibly they may have been formed, as in Croll's hypothesis, by a "grazing" collision between two dark bodies of large size. Dr. Roberts thinks that the globular clusters of stars have probably been evolved from spiral nebulæ, and Schaeberle has recently found evidence of spiral structure in the great globular cluster in Hercules (13 Messier).[1]

Admitting that suns and stars have been evolved in some way from nebulous masses, let us now try and follow their life history from the time that they have sufficiently consolidated to present the appearance of a star down to the distant time when they shall have lost all their heat and light by radiation, and "roll through space a cold and dark ball." It has been known for ages that the stars are of different colours—white, yellow, orange, and red—and this fact suggested some

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[1] *The Astronomical Journal*, No. 552, December 31, 1903.

essential physical difference between them; but until the discovery of the principles of spectrum analysis, it was impossible to determine their chemical composition. The application of spectrum analysis to the observation of stars and nebulæ now forms an important and interesting branch of astronomy, known as Astrophysics. The pioneer in this department of astronomical research was Dr. (now Sir William) Huggins, who, in 1856, erected an observatory in connection with his private house at Upper Tulse Hill, London. His first instrument was a telescope of 5 inches aperture by Dollond; but in 1858 this was replaced by one of 8 inches in diameter, the work of the famous American optician Alvan Clark. For the first few years he worked in conjunction with Dr. Miller, but afterwards by himself. In 1870 he obtained a loan from the Royal Society of a larger instrument, the work of Sir Howard Grubb. This instrument consisted of a 15-inch refractor and a 15-inch Cassegrain reflector mounted on the same stand. Having designed a suitable star spectroscope for this instrument, he first directed his attention to the brighter stars—Sirius, Vega, Aldebaran, etc.—and succeeded in comparing their spectra with those of terrestrial substances, such as hydrogen, iron, sodium, etc., and proved the existence of these elements in the stars referred to. About the same time similar observations were made independently by Rutherford in America, Secchi at Rome, and Vogel in Germany.

Remembering Sir William Herschel's views as to the probably gaseous nature of some of the nebulæ, Dr. Huggins determined to test the question by a spectroscopic examination. On the evening of August 29, 1864, he turned his spectroscope for the first time on the planetary nebula in Draco, which lies near the pole of the ecliptic. To his surprise, he found that the spectrum consisted of only one *bright* line instead of the continuous spectrum crossed by *dark* lines, which he had found in the spectra of the stars. On closer examination, he detected two other bright lines towards the blue end of the nebular spectrum. This decided the question, and proved beyond all doubt that the light emitted by this nebula came from glowing gas. The question then arose as to the chemical character of these bright lines, and later observations have shown that the two fainter lines are due to hydrogen; but the origin of the brightest line—the "chief nebular line," as it is called—still remains undetermined. It is probably due to some hitherto undiscovered chemical substance, and to this substance the name "nebulium" has been given. There is another line in the spectrum, also apparently due to the unknown substance, and photographs have disclosed the existence of some forty lines or more in various nebulæ, showing the probable presence of helium, carbon, iron, calcium, and probably magnesium. Of sixty of the brightest nebulæ and clusters, Dr. Huggins found that one-third showed the bright-line spectrum. Among these were the so-called planetary nebulæ and the great nebula in Orion. He found the great nebula in Andromeda to show a faint continuous spectrum, so that, nebulous looking as this wonderful object is, it is probably not truly gaseous. All the spiral nebulæ seem to show a continuous spectrum. Gaseous nebulæ are usually of a bluish or greenish colour, while those with a continuous spectrum are dull white.

Stars differ in the character of their spectra, and these spectra have been divided into several types. The 1st, or Sirian type, has the hydrogen lines very strong, and the lines of the metallic elements very faint, or invisible. In the 2nd, or solar type, the metallic lines are numerous and very visible. The 3rd type shows spectra in which, besides the metallic lines, there are numerous dark bands in all parts of the spectrum, and the blue and violet portions are very faint. This type has been sub-divided into two types—one in which the dark bands are fainter towards the red end of the spectrum, and the other in which these bands are fainter towards the violet. This latter type is now known as type IV. Stars of the 3rd and 4th types are much less numerous than those of the 1st and 2nd types; but there are about

1000 stars of the 3rd type now known, and 250 of the 4th type. Stars of the 5th type, which are also known as Wolf-Rayet stars, from their discoverers, are comparatively rare. They have a spectrum which, according to Professor Pickering, consists of "wide, bright bands superposed on a faint continuous spectrum, the strongest one of them probably coincident with a bright band in the spectrum of the gaseous nebulæ, and most of the others probably coincident with hydrogen lines and prominent Orion lines." The stars of types I. and V. are usually of a white colour; those of type II., yellow; type III., orange red; and type IV., all red. Most of the long-period variables have 3rd and 4th type spectra. There is a variety of type I. known as the "Orion type," many of the stars in Orion showing this type of spectrum. Between all these types there are many transitional types.

The question now arises, which of these various types represent the oldest and which the youngest stars? That is, which are nearest to the nebular stage, and which are farthest advanced in their "life history"? From an examination of a large number of stellar spectra, Professor Pickering is disposed to think that stars showing the "Orion type" of spectrum are probably "in an early stage of development," and that stars with spectra of the 5th type may possibly form a connecting link between the Orion stars and those of the nebulæ."

After the Orion stars come the stars of the 1st type (the Sirian), then those of the 2nd (the solar), and lastly the 3rd type, which is the oldest, and probably belongs to stars which are approaching the total extinction of their light. The 4th type may also represent stars far advanced in their "life history," but their relation to the 3rd type stars is not very obvious. In this view of the evolutional order Sir William Huggins concurs. In his address to the British Association at Cardiff in 1891, he said, "This order is essentially the same as Vogel had previously proposed in his classification of the stars in 1874, in which the white stars, which are the most numerous, represent the early adult and most persistent stage of stellar life, the solar condition that of maturity and of commencing age; while in the orange and red stars we see the setting in and advance of old age." At that time he considered that the order of evolution was represented by the following stars:—Sirius and Vega, α Ursæ Majoris, α Virginis, α Aquilæ, Rigel, α Cygni, Capella, and the sun, Arcturus, Aldebaran, and Betelgeuse, the first named being the youngest, and the last the oldest.

That stars of the "Orion" and the Sirian types are of less density than those of the solar type has been recently shown by Roberts and Russell, who have made calculations respecting the densities of the Algol type variables, which all show spectra of the "Orion" or Sirian type. These investigations show that the average density of these stars is much less than that of the sun,[1] and that, therefore, they are in an earlier stage of condensation. The same remark applies to Sirius itself, which has a small mass in proportion to its brightness, indicating that it is probably a body with a large volume, high temperature, and small density.

Stars in the earlier stages of evolution have probably no well-developed photosphere, and being greatly expanded by heat, and of small density, a large proportion of their light comes to us from a greater depth below their surface than in stars of the solar type.

It has been shown by Homer Lane, an American physicist, that so long as a star "remains subject to the laws of a purely gaseous body, its temperature will increase as condensation advances." When, however, owing to the continual radiation of heat the gaseous state has been passed, the star will begin to cool, its light will diminish, and changes will take place in its spectrum. Sir William Huggins is now disposed to think that the hottest stars must be looked for among those of the Solar type. The "evolutional order" now adopted by him seems to be (omitting the so-called Wolf-Rayet stars) Bellatrix, Rigel, α Cygni, Regulus Vega, Sirius, Castor (fainter component), Altair, Procyon, γ Cygni, Capella (hottest star), Arcturus, and Betelgeuse; the youngest being

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[1] *The Astronomical Journal*, vol. 10, p. 308.

Bellatrix, and the oldest Betelgeuse. The order would then be:—Nebulæ, "Orion type," type I., type II., and type III. The exact position of type IV. has been considered doubtful, but from a recent elaborate discussion of their spectra, Professor Hale thinks that "4th type stars probably develop from stars like the sun through loss of heat by radiation." Types III. and IV. are therefore collateral branches of development from the sun, as Vogel regarded them. Hale finds a close agreement between the spectra of the 4th type stars and those of sun-spots, and he suggests that these stars may be covered with numerous sun-spots.[1]

There are many long-period variables with spectra of the 3rd and 4th types. These are probably suns which have far advanced in the process of condensation and cooling, and are subject to periodical outbursts of light, owing to the escape of imprisoned gases. This is suggested by the appearance of bright lines in the spectra of many of them near the time of maximum light. This process might go on for centuries, or even thousands of years, until at last the whole mass of the star would become so cooled down that there would be no further outbursts of light. The star would then cease to rise to a maximum, and it would slowly diminish in brightness, until its light became wholly extinguished. One stage of

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[1] *Publications of the Yerkes Observatory*, vol. 3, part 5.

this process would seem to have been actually reached in the case of the long-period variable T. Ophiuchi. Discovered by Pogson in 1860, it was found to be variable from the 10th to the 12th magnitude in a period of about 361 days between the maxima, but for the last sixteen years it has not risen to a maximum, and remains at a permanent minimum of light. In the course of time this star will probably slowly diminish until it becomes wholly extinguished, and it will then "roll through space a cold and dark ball." Possibly this may be the ultimate fate of our own sun, and of the thousands of stars which now sparkle in our midnight sky.

XVI

The Construction of the Visible Universe

AN examination of the evidence we have at present with reference to the distribution of the visible stars in space has recently been undertaken by Professor Kapteyn, of Groningen, and a popular account of the conclusions he has arrived at may prove of interest to the general reader.

It must first be explained that, in order to obtain a clear view of the construction of the visible heavens, it would be necessary to know the relative distances of a large number of stars; but as the distances of only a few stars have yet been determined, and the results hitherto obtained are open to much uncertainty, we must have recourse to some other method of estimating these distances. In travelling in a railway carriage, if we fix our attention on the trees, buildings, and other objects we pass on our journey, it will be noticed that all objects apparently move past us in the opposite direction to that in which we are travelling, and that the nearer the object is, the faster it seems to move, with reference to distant objects near the horizon. The telegraph-poles and mile-posts fly past rapidly, while trees and houses at some distance have a much slower apparent motion. So it is with the stars. The sun is moving through space, carrying along with it the earth and all the planets, satellites, and comets forming the solar system. The effect of this motion is to cause an apparent small motion of the stars in the opposite direction, and the nearer the star is to the earth the greater will be this apparent motion —as in the case of a railway train. In addition to this apparent motion, the stars are themselves—like the sun—moving through space, and this *real* motion is also visible; that is, it can be measured by accurate astronomical observations. If this *real* motion takes place in the *opposite* direction to that in which the earth is moving, it will add to the apparent motion, and will increase the "proper motion," as it is termed. If, on the other hand, the real motion is in the *same* direction as the earth's motion, it will tend to diminish the proper motion. In either case, the nearer the star is to the earth the greater will be its apparent annual displacement on the background of the heavens. The amount of this "proper motion" is, therefore, considered by astronomers to form a reliable criterion of the stars' distance from the earth, and the actual measures of distance which have been made show that this assumption is approximately true. Of fourteen stars which have a proper motion of over three seconds of arc per annum, eleven have yielded a measurable parallax, or displacement due to the earth's annual motion round the sun; that is to say, that eleven out of fourteen fast-moving stars are within a measurable distance of the earth, and therefore near us when compared with the great majority of the stars which are not within measurable distance, or, at least, are beyond our present methods of measurements.

In the case of small groups of stars, we may assume that the real motions of the individual stars take place indifferently in all directions, and that consequently, taking an average of all the motions of the stars composing the group, the effects due to the real motions will destroy each other, and there will remain, as the most reliable criterion, the effect due to the sun's motion in space. If, however, we compare the proper motions of groups situated in *different parts* of the sky, there is a consideration which, to a great extent, vitiates this conclusion; for, near the point of the heavens *towards* which the sun and earth are moving, known as the *apex of the solar way*, and probably situated somewhere near the bright star Vega (as indicated by recent researches); and near the point *from* which the sun is moving—known as the *ant-apex*, about 20° south of Sirius—there will be no apparent displacement due to the solar motion in space, as this motion takes place in the line of sight with reference to these points of the sky. The observed proper motions at these points will, therefore, be solely due to the real motion of the stars in those regions. In other parts of the heavens, however, the total proper motion will be a combination of the apparent and real motions of the stars, and for stars in *different* parts of the heavens it will not follow that stars having equal proper motions are necessarily at the same distance from the earth. To make this point clearer, let us assume that there are two stars at absolutely the same distance from our eye, one situated at or near the solar apex, and the other at a point 90° from the apex, and let us suppose that both are moving through space with exactly the same velocity, and in the same direction—say at right angles to the direction of the solar motion. Then, in the case of the star near the "apex," the observed "proper motion" will be solely due to the star's *real motion*, and in the star 90° distant from the apex the "proper motion" will be solely due to the solar motion. Now, unless the stellar motion and the solar motion happen to be equal, the observed "proper motions" will not be equal, although both stars are at the same distance from the earth, and are moving with the same velocity. If both stars are really at rest, the star at the "apex" will have no proper motion, while the star 90° distant will have an *apparent* motion due to the sun's motion. To overcome this source of error in estimating the distance of a star from its proper motion, Professor Kapteyn made use of another measure which is independent of the solar motion. This is the component of the proper motion measured at right angles to a great circle of a sphere passing through a star and the solar apex. The amount of motion in this direction will evidently not be affected by the sun's motion; and from a discussion of the stars contained in the "Draper Catalogue of Stellar Spectra," which were observed by Bradley (and of which the proper motions are now known with accuracy), Professor Kapteyn finds that this motion is "nearly inversely proportional to the distance;" that is, the greater the motion the less the distance of the stars, and the smaller the motion the greater the distance. Excluding stars with proper motions greater than half a second of arc per annum, Professor Kapteyn found that for stars at various distances from the Milky Way this component of the "proper motion" forms a good measure of distance.

As the result of his investigations on this interesting question, Professor Kapteyn arrives at the following conclusions:—

Neglecting stars with small or imperceptible proper motions, we have a group of stars which no longer show any condensation in a plane.

Stars with very small or no proper motions show a condensation towards the plane of the Milky Way. This applies to stars of the 2nd, or solar, type, as well as to those of the 1st, or Sirian, type of spectrum, and evidently indicates that the stars composing the Milky Way lie at a great distance from the earth. The extreme faintness of the majority of the stars composing the Galaxy seems to confirm this conclusion. The condensation of stars of the 1st, or Sirian, type is more marked than those of the 2nd, and this agrees with the fact found by Professor Pickering, that the majority of the brighter stars of the Milky Way show spectra of the 1st type. Judging from the ease with which the fainter stars of the Galaxy can be photographed, he concludes that most of these fainter stars are bluish, and probably have spectra of the 1st type, like Sirius and Vega, which are bluish-white. From an enumeration of the stars included in the "Draper Catalogue," I find that 63 per cent. of the stars on the Milky Way, as drawn by Heis, have spectra of the 1st type.

Professor Kapteyn finds that this condensation of stars with small proper motions is very perceptible, even for the stars visible to the naked eye, and is as well marked in those stars which have spectra of the 2nd type as for all stars of the 9th magnitude; but for stars of the 1st type the condensation is still more marked. He considers that this condensation is either partly real, or that there is a real thinning out of stars near the pole of the Milky Way. As I have shown elsewhere, M. Celoria's observations with a small telescope, compared with Sir William Herschel's observations with a large telescope, indicate clearly that there *is* a *real* thinning out of stars near the poles of the Milky Way.

Professor Kapteyn concludes that the arrangement of the stars suggested by Struve has no real existence. He attributes the fallacy in Struve's hypothesis to the fact that the mean distance of stars of a given magnitude in the Milky Way and outside it is not the same. He finds that the vicinity of the sun is almost exclusively occupied by stars of the 2nd, or solar, type, a conclusion which reminds us of Dr. Gould's "solar cluster." He thinks that the number of Sirian-type stars increases gradually with the distance, and that beyond a distance corresponding to a proper motion of about one-fourteenth of a second per annum the Sirian stars largely predominate.

In the group of stars known as the Hyades, however—of which Aldebaran is the leading brilliant—the components of which have a common proper motion, both in amount and direction, stars of the 1st and 2nd type seem to be mixed, and Professor Kapteyn assumes that the two types represent different phases of evolution, and that, as the brightest stars of the group are chiefly of the solar type, these stars must be the largest of the cluster. From this fact he concludes that the solar-type stars are in a less advanced stage of evolution than those of the Sirian type. This does not, however, agree with the generally accepted view. Sir William Huggins and Professor Vogel consider the Sirian stars to represent an earlier stage of stellar evolution. Proctor held the same opinion. In Sir Norman Lockyer's hypothesis of increasing and decreasing temperatures in stars of various types of spectra, he places the Sirian stars at the summit of the heat curve, and the sun and solar stars just below them on the descending branch of the curve.[1] This view is in conformity with the current opinion that the sun is a cooling body. In the case of the Pleiades, which form a more evident cluster than the Hyades, I find from the "Draper Catalogue" that the great majority of the brighter stars have spectra of the Sirian type. Most of these stars have a very similar proper motion, both in direction and amount, and there can be little or no doubt that they form a connected system. The superior brilliancy of the stars composing the Hyades would perhaps indicate that they are nearer to the earth than the Pleiades group, and they may possibly form members of "the solar cluster."

Assuming that the distances of the stars are

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[1] "The Meteoritic Hypothesis," pp. 380, 381.

inversely proportional to their proper motions, Professor Kapteyn computes the relative volumes of the spherical shells which contains the stars with different proper motions (from one-tenth of a second to one second of arc, and more). Comparing these volumes with the corresponding number of stars, we arrive at an estimate of the density of star distribution at various distances. The result of this calculation shows that the distribution of stars of the Sirian type approaches uniformity when a large number of the faint stars (the 9th magnitude) are considered. With reference to stars of the 2nd, or solar, type, however, the larger the proper motion the greater the number of the stars, or, in other words, the 2nd type, or solar stars, are crowded together in the sun's vicinity. Evidence in favour of this conclusion is afforded by the fact that of eight stars having the largest measured parallax (and whose spectrum has been determined), I find that seven have spectra of the solar type. The exception is Sirius, which is evidently an exceptional star, with reference to its brightness and comparative proximity to the earth, no other star of the 1st magnitude having so large a parallax.

Professor Kapteyn finds that the centre of greatest condensation of the solar-type stars lies near a point situated about 10° to the west of the great nebula in Andromeda, and that this centre nearly coincides with the point which, according to Struve and Herschel, represents the apparent centre of the Milky Way considered as a ring. This would indicate that the sun and solar system lie a little to the north of the plane of the Milky Way, and towards a point situated in the northern portion of the constellation of the Centaur. The fact is worth noting that the nearest fixed star to the earth, Alpha Centauri, lies not very far from this point. Possibly there may be other stars in this direction having a measurable parallax. The southern portion of the heavens has not yet been thoroughly explored for parallax.

For stars of equal brightness, Professor Kapteyn finds that those of the Sirian type are, on an average, about 2¾ times farther from the earth than those of the solar type. As light varies inversely as the square of the distance, this would imply that the Sirian stars are intrinsically over 7 times brighter than those of the solar type. This conclusion is confirmed by the great brilliancy of Sirius, and other stars of the same tppe in proportion to their mass. I have shown in the chapter on the "Suns of Space" that Sirius is about 31 times brighter than our sun would be if placed at the same distance, although its mass is only 2·36 times the sun's mass, as computed from the orbit of its satellite.

The general conclusions to be derived from the above results seem to be that the sun is a member of a cluster of stars possibly distributed in the form of a ring, and that outside this ring, at a much greater distance from us than the stars of the solar cluster, lies a considerably richer ring-shaped cluster, the light of which, reduced to nebulosity by immensity of distance, produces the Milky Way gleam of our midnight sky.

XVII

The Secular Variation of Starlight

THE "secular variation" of the stars, that is, the slow increase or decrease of their light in the course of ages is an interesting subject, and has an obvious bearing on the question of stellar evolution. This secular variation must not be confused with the periodic variation to which a large number of stars are subject, nor with the "irregular" variation to which some stars are liable. Almost all the "long period" and "irregular" variables have spectra of the 3rd type, or "fluted spectra," and seem to belong to a distinct class—probably suns passing through the last stages of their life-history. "Short period" variables have usually spectra of the 2nd, or solar, type, and the "Algol variables"—which are not true variables, but merely eclipse stars—have spectra of the 1st type. Stars affected by "secular variation" must be looked for among those with spectra of the 1st and 2nd types. When a star reaches the 3rd type it seems to become either periodically or irregularly variable. Stars with secular variation might be expected to be *apparently* constant in their light, the secular variation being so slow that no change can be detected in a few years' observation. This change may, however, possibly become appreciable in the course of centuries, at least in some cases. According to Lane's law, a mass of incandescent gas in contracting rises in temperature, and therefore probably in light, "as long as the gaseous condition is retained," but when condensation has further advanced the mass would begin to cool and the light of the star would then slowly diminish.

In my examination of Al-Sufi's "Description of the Fixed Stars," written in the 10th century, I have noticed a number of cases in which a star seems to have either increased or diminished in brightness. In addition to his own estimates, Al-Sufi gives the magnitudes as rated by Ptolemy (or Hipparchus), and these are valuable, as Ptolemy's magnitudes, given in all the editions of the "Almagest," now extant, are quite untrustworthy. Ptolemy's magnitudes are probably those of Hipparchus, and this would take us back to B.C. 127, or over 2000 years ago. A period of 2000 years is, of course, very short in the life-history of a star, but as, according to the theory of stellar evolution, a star would, beginning with the nebulous stage, go on for ages increasing in light, then remain stationary for a long period, and after that slowly diminish in brightness, it seems possible that some perceptible changes may have taken place in certain stars since the time of Hipparchus. We know that some stars have *certainly* decreased in brightness since they were observed by Al-Sufi. For example, there can be no doubt that the star β Leonis (Denebola) has diminished from the 1st to the 2nd magnitude since the 10th century. Al-Sufi describes it in the same words that he uses with reference to Regulus, namely, "the bright and great star of the 1st magnitude." The same may be said of θ Eridani, which has faded from the 1st to the 3rd magnitude. Some writers have suggested that the star mentioned by Al-Sufi was not θ Eridani, but α Eridani (the so-called Achernar), and that Al-Sufi merely described α Eridani from the descriptions of travellers! But this Al-Sufi never did in the case of *any* star mentioned in his book. He was much too careful and conscientious an observer to do anything of the sort, and he expressly states in the preface to his work that he has described all the stars he speaks of "as seen with my own eyes." Moreover, his description of the position of the star he observed as "1st magnitude," and the neighbouring stars in Eridanus, is so clear as to leave no room for doubt as to the identity of the star with θ Eridani. That this is the correct interpretation of Al-Sufi's statement was also the opinion of Ulugh Beigh, Halley, Baily, and Dr. Anderson. Further, Hipparchus and Ptolemy state distinctly that the "Last in the River" rose above their horizon at a certain time of the year, and this α Eridani could not possibly have done. This seems sufficient to finally settle the question in favour of θ Eridani, which is, therefore, the real Achernar, or "Last in the River" of Ptolemy."[1]

The following are a few of the most interesting and remarkable cases of apparent increase or decrease of light which I have met with in Al-Sufi's work. I will first consider stars which have probably decreased in brightness.

β Aquilæ. This is the southern of the three well-known stars in Aquila, γ, Altair, and β, which lie nearly in a straight line. β was rated 3rd magnitude by Ptolemy, 3–4 ("small third") by Al-Sufi, 4 by Argelander, Heis, and Houzeau, and was measured 3·90 with the photometers at Harvard and Potsdam. The spectrum is of the 2nd type (K, Pickering), which probably indicates a cooling star. Ptolemy (or Hipparchus) rated β and γ as both 3rd magnitude, but at present β is one magnitude fainter than γ. The ancients called the two stars *al-mîzân*, "the balance," probably on

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[1] For further particulars, see an interesting paper by Dr. Anderson on "The Story of Theta Eridani," in *Knowledge*, July, 1893. I venture to suggest that θ Eridani should be called Eschatos, to show that it is identical with the Εσχατος τοῦ ποταμοῦ of Ptolemy and Ulugh Beigh.

account of the equality of the stars—one on each side of Altair.

κ Libræ. Rated 4th magnitude by Ptolemy and Al-Sufi, 5 by Argelander, Heis, and Houzeau, and measured 4·96 at Harvard. Al-Sufi made it equal to γ Libræ (4m., as it is at present), but κ is now nearly a magnitude fainter than γ. Al-Sufi made κ one magnitude brighter than 37 Libræ (5, about its present brightness), but they are now equal. κ has therefore diminished from the 4th to the 5th magnitude, while 37 has probably remained constant in light. Both Ptolemy and Al-Sufi rated κ two magnitudes brighter than χ, but they are now practically equal. The spectrum of κ is of the 2nd type (H, Pickering), and is probably a cooling star.

7 (*b*) Piscium. 4 Ptolemy, 4–5 Al-Sufi, 6 Argelander, 6–5 Heis, 5 Houzeau, 5·20 Harvard. Spectrum H. Ptolemy and Al-Sufi made it equal to γ Piscium, but at present it is more than a magnitude fainter. Argelander made it *two* magnitudes less than γ, and there can be little or no doubt that it has diminished in brightness. γ is still about 4th magnitude, as Ptolemy rated it.

θ Eridani has been already referred to. Its spectrum is intermediate between the 1st and 2nd types (A 2 F), and is similar to that of β Leonis.

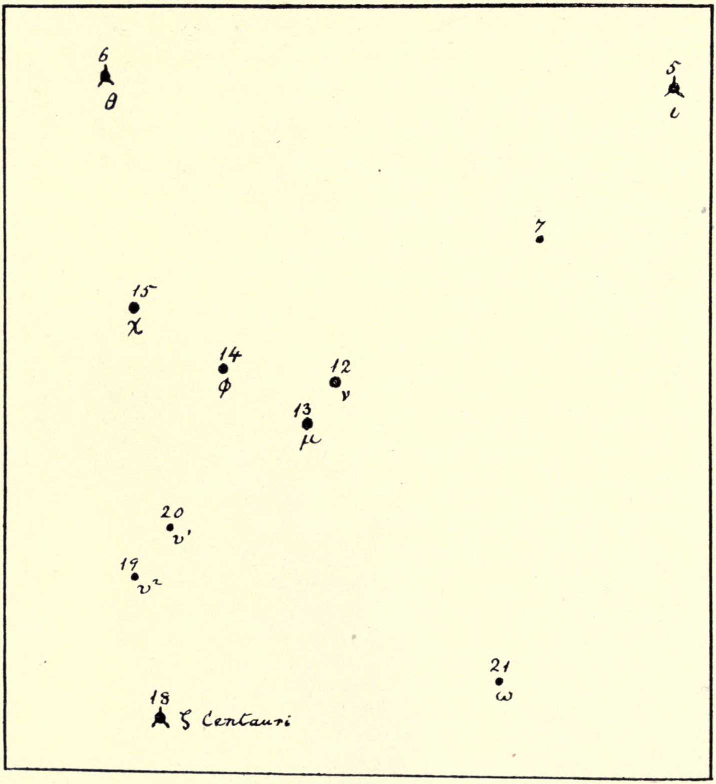
β Hydræ. Rated 3rd magnitude by Ptolemy and Al-Sufi, 4 by Argelander and Heis, 4-5 by Houzeau, 4·40 Harvard, and 4·5 at Cordoba.

Al-Sufi made it slightly brighter than γ Hydræ (3–4 Al-Sufi, 3·33 Harvard), but it is now a magnitude fainter. This seems a certain case of diminution in brightness.

ζ Piscis Australis. 4 Ptolemy, 5–6 Al-Sufi, Argelander, and Heis, 6–5 Behrmann, 6 Houzeau, 6·62 Harvard, 6·7 Cordoba. This star seems to have certainly diminished.

η Piscis Australis. 4 Ptolemy, 5 Al-Sufi, 5·6 Argelander, Heis, and Houzeau, 5·47 Harvard, 5·7 Cordoba.

χ Centauri. Rated 4–3 by Ptolemy and Al-Sufi, 4–5 by Houzeau, 4·54 Harvard, 4·8 Cordoba, 4·75 Williams. Here we have a case of certain diminution of light. The stars ν, μ, ϕ, and χ Centauri lie near each other between θ and ζ Centauri. Al-Sufi's remarks with reference to these four stars are very interesting, and his description very clear and unmistakable. He says: "The 12th (ν) is of large 4th magnitude [3·53 Harvard], and is on the left side [of the ancient figure]. The 13th and 14th (μ and ϕ) are behind the 12th [that is in longitude] and near it; as to the 13th (μ), it is the more southern of the two, below the 12th (ν); it is also of large 4th magnitude [3·32 Harvard]. Between these two stars there is a span [about 47′]. The 14th (ϕ) is behind the 13th (μ), and of the 4th magnitude [4·05 Harvard]. Ptolemy calls larger [4–3], although it is of less brightness than the 12th and 13th [as it is at present]. These



STARS IN CENTAURUS (AL-SUFI).

stars, the 12th, 13th, and 14th (ν, μ, and ϕ) are close together, forming a little triangle, and are all in the right side, to the south of the 7th (*d*, between ι and ν). The 15th (χ) follows these three stars, inclining towards the north; between it and the 14th (ϕ) there is less than a cubit [that is, less than 2° 20′]. It is of large 4th magnitude." At present χ is distinctly fainter than ϕ, although rated brighter by Al-Sufi. It is also one magnitude fainter than ν, which Al-Sufi rates of the same magnitude (4–3). A glance at the accompanying map will show how minute and accurate Al-Sufi's description is, leaving no doubt as to the identity of the stars he refers to.[1]

o Persei. This is another case of apparently certain diminution of light. It was rated "small 3rd magnitude" by Ptolemy and Al-Sufi, 4 by Argelander and Heis, and was measured 3·94 at Harvard, and 3·85 at Potsdam. Ptolemy and Al-Sufi agree in making it equal to ζ [2·91 Harvard], which lies near it, but the Harvard measures make *o* about one magnitude fainter than ζ, and their present great disparity in brightness is noticeable at a glance. Al-Sufi's description of the two stars is clear, and leaves no room for doubt as to their identity. I have plotted Ptolemy's positions of these stars, and find that they agree well with Al-Sufi's description. Al-Sufi says: "The 25th (*o*)

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[1] The stars shown in the map are plotted from Ptolemy's positions.

is the preceding of two stars which are in the left leg, and is found in the heel [of the ancient figure of Perseus]. It is of small 3rd magnitude. The 26th (ζ) is the following, and between them to the eye there is about a cubit (2° 20′). It is also of small 3rd magnitude, and these two stars are the nearest to the Pleiades; there is no star between them and the Pleiades." Al-Sufi's estimates of star-magnitudes in this vicinity are remarkably accurate. He rated ξ Persei 4th magnitude (4·05 Harvard), ε, 3rd magnitude (2·96 Harvard), and ν, 4th magnitude (3·93 Harvard), and Ptolemy agrees with his estimates. We must, therefore, conclude that ο Persei has diminished in brightness from the 3rd to the 4th magnitude since Al-Sufi's time. This is one of the most remarkable cases I have met with in Al-Sufi's work. The stars are close together, and can be easily compared, so that no mistake as to their relative brightness seems possible. ο Persei has recently been found to be a "spectroscopic binary," with a period of 4·39 days. Both components are bright bodies, and Vogel finds a minimum mass of $\frac{3}{5}$ of the sun's mass. The orbital velocity is about 68 miles a second, and the distance between the components about 4 millions of miles.

Let us now consider some stars which have probably *increased* in brightness since Al-Sufi's time.

σ Serpentis. This star is not mentioned by

Ptolemy, but Al-Sufi rated it 6th magnitude. It was estimated 5th magnitude by Argelander, Heis, and Houzeau, and was measured 4·80 at Harvard. Al-Sufi rated it two magnitudes fainter than 66 Ophiuchi, but at present the two stars are almost exactly equal (4·80 and 4·81 Harvard). One has apparently increased and the other diminished.

ω Tauri. This star, which lies a little north of the Hyades, was rated 6th magnitude by Ptolemy and Al-Sufi, 6–5 by Argelander and Heis, 5 by Houzeau, and was measured 4·80 at Harvard. Al-Sufi made it one magnitude less than *p* (44) Tauri, but it is now considerably brighter than *p*, and seems to have certainly increased in brightness.

γ Geminorum. Rated 3rd magnitude by Ptolemy and Al-Sufi, 2–3 by Argelander, Heis, and Houzeau, and measured 1·93 at Harvard. Ptolemy and Al-Sufi rated it equal to δ Geminorum, but γ is now $1\frac{1}{2}$ magnitude brighter than δ. This is one of the most remarkable cases I have met with in Al-Sufi's work. δ is now about $3\frac{1}{2}$ magnitude, and may perhaps have faded a little; but it seems evident that γ must have increased by about one magnitude. Its spectrum is of the Sirian type.

β Canis Majoris. 3m. Ptolemy and Al-Sufi, 3–2 Argelander and Heis, 2 Houzeau, 1·99 Harvard. Al-Sufi made it equal to ζ (3·10 Harvard), but it is now a magnitude brighter. The spectrum is of the "Orion type" (B 1 A, Pickering).

109 Herculis. This star was not mentioned by Ptolemy, but Al-Sufi rated it a large 6th magnitude (6–5). It was estimated 4 by Argelander and Heis, 4–5 by Houzeau, and was measured 3·92 at Harvard.

β Eridani. Rated 4th magnitude by Ptolemy and Al-Sufi, 3 by Argelander and Heis, 3–4 Houzeau, 2·8 at Cordoba, and 2·92 at Harvard. Al-Sufi rated it equal to λ Eridani (4·34 Harvard), but it is now about $1\frac{1}{2}$ magnitude brighter than λ, and it seems to have certainly increased in brightness since Al-Sufi's time.

To the above we may, perhaps, add η Tauri (Alcyone in the Pleiades), which is apparently not mentioned by Ptolemy or Al-Sufi, and has probably increased considerably in brightness since ancient times. Spectrum, B 5 A, Pickering.

XVIII

The Herschels and the Nebulæ

A LARGE number of those interesting and mysterious objects, the nebulæ, were discovered by the illustrious astronomer, Sir William Herschel, and his famous son, Sir John Herschel, and some account of their labours in this branch of astronomy may prove of interest to the general reader.

In the year 1783 Sir William Herschel began a series of observations—or "sweeps" of the heavens, as he termed them—with a view to gain some knowledge respecting what he called "The Interior Construction of the Universe." In the course of these "sweeps" he discovered a considerable number of new nebulæ and clusters of stars not noticed by previous observers. The instrument used in this research was a Newtonian reflector of 18·7 inches aperture and 20 feet focal length, the power used in "sweeping" being 157 diameters, and the field of view 15′ 4″, or about half the apparent diameter of the moon. Herschel's first catalogue of "One Thousand New Nebulæ and Clusters of Stars" appeared in the *Philosophical Transactions* of the Royal Society for the year 1786. In this catalogue he gives the approximate position of each nebula and cluster, with an abridged description of its general appearance as seen in his telescope, this description being dictated to and written down by an assistant while the great astronomer had the object actually before his eye.

The catalogue is divided into eight classes. The first class includes "bright nebulæ;" the second class, "faint nebulæ;" the third class, "very faint nebulæ;" the fourth class, "planetary nebulæ;" the fifth class, "very large nebulæ;" the sixth class, "very compressed and rich clusters of stars;" the seventh class, "pretty much compressed clusters of large or small stars;" and the eighth class, "coarsely scattered clusters of stars." In the *Philosophical Transactions* for 1789 he gives a second catalogue of 1000 new nebulæ and clusters which form a continuation of the first catalogue. These two catalogues include 215 objects of the first class, 768 of the second, 747 of the third, 58 of the fourth, 44 of the fifth, 35 of the sixth, 55 of the seventh, and 78 of the eighth. An example or two taken from each class and compared with modern observations of these objects may prove of interest to the reader.

No. 6 of Class I. lies following the star 64 (Flamsteed) Virginis, and is thus described by Sir

William Herschel: "Very bright, pretty large, gradually much brighter in the middle."

No. 47 of Class I. follows 1 Aquilæ, and Herschel says it is "bright, very large, of an irregular figure, easily resolvable, stars visible." Webb says, "Beautiful resolvable nebula."

No. 162 of Class II. lies a little preceding the star 34 Virginis, and is described by Herschel as "not very faint, pretty large, irregularly round, a little brighter towards following side."

Nos. 129 and 130 of Class III. lie north following the star σ Boötis, and are described as "two, about 6 minutes distant, both extremely faint, very small, round, verified with 240."

No. 26 of Class IV., or "planetary nebulæ," lies about 4° following the star γ Eridani, and is described by Herschel as "very bright, perfectly round, or very little elliptical, planetary but ill-defined disc. Second observation, resolvable on the borders, and is probably a very compressed cluster of stars at an immense distance." Admiral Smyth describes it in 1837 as "a splendid though not very conspicuous object, of a greyish white colour; it is somewhat like a large star out of focus, with a planetary aspect." Lassell described this curious nebula as "the most interesting and extraordinary object of the kind" he had ever seen. d'Arrest, like Herschel, found the edges resolvable, and Huggins finds that the spectrum is *not* gaseous.

No. 43 of Class V. is described by Herschel as "very brilliant, 15′ long, running into very faint nebulosity extending a great way." Smyth says, "A large white nebula . . . a noble-sized oval . . . with a brightish nucleus in its southern portion; the lateral edges are better defined than the ends." Webb says, "Large, oval, bright, best defined at edges, nucleus south, like Andromeda nebula on a small scale. Spectrum continuous." It lies a little south of the star 3 Canum Venaticorum.

Herschel describes his No. 10 of Class VI., which lies a little north preceding α Scorpii (Antares), as "a very compressed and considerably large cluster of the smallest stars imaginable, all of a dusky red; the next step to an easily resolvable nebula." That all the stars should be of a *red* colour is remarkable. Sir John Herschel says, with reference to this cluster, "Pretty large, oval, gradually brighter in middle, resolvable."[1]

No. 30 of Class VI. was discovered by Miss Caroline Herschel, Sir William Herschel's famous sister, and is described as "a beautiful cluster of very compressed small stars, very rich." It lies a little south of ρ Cassiopeiæ, and between that star and σ Cassiopeiæ. Admiral Smyth describes it (1835) as "a very glorious assemblage, both in extent and richness, having spangly rays of stars which give it a remote resemblance to a crab, the claws reaching the confines of the space in view,

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[1] "Cape Observations," p. 111.

under an eyepiece magnifying 185 times . . . The crab itself is but a mere condensed patch in a vast region of inexpressible splendour, spreading over many fields." Photographs taken by Dr. Roberts in 1892 and 1898 show "lines, wreaths, and curves of stars," which he thinks "give evidence of their formation, or arrangement, by vortical movements similar in character to those shown in the spiral nebulæ." The individual stars are distinctly seen on the negative, and could be easily counted.

No. 2 of Class VII. lies north following the star 8 Monocerotis, and is described by Herschel as "a beautiful cluster of scattered stars, the first large, the second arranged in winding lines. Contains the 12th Monoceros." Webb says, "Beautiful, visible to the naked eye; including 12, 6th magnitude, yellow; and many 7 and 8 magnitude stars. The smallest, 14th magnitude, run in rays. Small pair near centre." Near this cluster Professor Lewis Swift sees "a wonderful nebulous ring."

No. 16 of Class VIII. follows ϕ Cygni, and is described by Herschel as "a cluster of not very compressed stars, closest in the middle. It may be called (if the expression be allowed) a forming cluster, or one that seems to be gathering."

A few of Herschel's nebulæ may have been telescopic comets. With reference to No. 7 of Class I., which lay a little following the star 49 Leonis, and which is described in the catalogue as "very bright, large, and round," Herschel says, in the notes to his first catalogue, "This remarkable appearance being no longer in the place it has been observed, we must look upon it as a very considerable telescopic comet. It was visible in the finder, and resembled one of the bright nebulæ of the *Connoissance des Temps* so much that I took it for one of them till I came to settle its place; but this not being done till a month or two after the observation, the opportunity of pursuing and investigating its track was lost;" and he says that No. 6 of Class II. was also probably "a telescopic comet, as I have not been able to find it again, notwithstanding the assistance of a drawing which represents the telescopic stars in its neighbourhood."

In the preface to his second catalogue, Herschel refers to the nebulæ "as being no less than whole sidereal systems." But this conclusion must now be modified to a considerable extent, as spectroscopic observations show that many of them are nothing but masses of glowing gas, and may lie well within the limits of our own sidereal system. With reference to the "planetary nebulæ," Herschel says they "may be looked upon as very aged, and drawing on towards a period of age or dissolution;" but as several of the "new" or "temporary stars" discovered in recent years have apparently changed into "planetary nebulæ," it would seem probable that these curious objects represent rather an early stage, and not a late one, of nebular formation. Herschel seems to have had an idea that there was some relation between planetary nebulæ and the phenomenon of a new star, for in a previous paper[1] he says, "If it were not, perhaps, too hazardous to pursue a former surmise of a renewal in what I frequently called the laboratories of the universe, the stars forming these extraordinary nebulæ, by some decay or waste of nature being no longer fit for their former purposes, and having their projectile forces, if any such they had, retarded in each other's atmosphere, may rush at last together, and, either in succession or by one general tremendous shock, unite into a new body. Perhaps the extraordinary and sudden blaze of a new star in Cassiopeia's Chair in 1572 might possibly be of such a nature." But the reverse of this seems now more probable, a planetary nebula being formed from a temporary star, not a temporary star from a planetary nebula.

In the *Philosophical Transactions* for 1791 there is a paper by Sir William Herschel on "Nebulous Stars," in which he expresses his opinion that the nebulosity surrounding these curious objects is not composed of stars. He says, "View, for instance, the 19th cluster of my 6th class, and afterwards cast your eye on this cloudy star. . . . Our judgment, I may venture to say, will be that *the nebulosity about this star is not of a starry nature*."[2] Among the nebulous stars described

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[1] *Phil. Trans.*, 1785, pp. 265, 266.

[2] The italics are Herschel's.

by Herschel in this paper, the following may be mentioned :—

"January 17, 1787.—A star with a pretty strong milky nebulosity, equally dispersed all round; the star is about the 9th magnitude. A memorandum to the observation says that, having just begun, I suspected the glass to be covered with damp, or the eye out of order; but yet a star of the 10th or 11th magnitude, just north of it, was free from the same appearance. A second observation calls it one of the most remarkable phænomena I have ever seen, and like my northern planetary nebula in its growing state. The connection between the star and the milky nebulosity is without all doubt." Sir John Herschel describes it as an 8th magnitude star, "exactly in the centre of an exactly round, bright atmosphere 25″ in diameter." Webb found a "bluish nebulosity, quite like a telescopic comet," and says, "the Earl of Rosse saw a marvellous object—a star surrounded by a small circular nebula, in which, close to the star, is a little black spot. This nebula is encompassed, first by a dark then by a luminous ring, very bright, and always flickering; perhaps a spiral. . . . A mass of luminous gas." This wonderful object lies south following the star 63 Geminorum.

"March 5, 1790.—A pretty considerable star of the 9th and 10th magnitude, visibly affected with a very faint nebulosity of little extent all around.

A power of 300 showed the nebulosity of greater extent. The connection is not to be doubted." This object lies a little south preceding the star 22 Monocerotis.

"November 13, 1790.—A most singular phænomenon! A star of about the 8th magnitude, with a faint luminous atmosphere, of a circular form, and about 3′ in diameter. The star is perfectly in the centre, and the atmosphere is so diluted, faint, and equal throughout, that there can be no surmise of its consisting of stars; nor can there be doubt of the evident connection between the atmosphere and the star. Another star, not much less in brightness, and in the same field with the above, was perfectly free from any such appearance." This object will be found about 2° north of the star ψ Tauri.

With reference to the constitution of these curious objects, Herschel rejects the idea that the luminous atmosphere is composed of small stars, and says, "We therefore either have a central body which is not a star, or have a star which is involved in a shining fluid, of a nature totally unknown to us," and he adds, "But what a field of novelty is here opened to our conceptions! A shining fluid, of a brightness sufficient to reach us from the remote regions of the 8th, 9th, 10th, 11th, or 12th magnitude, and of an extent so considerable as to take up 3, 4, 5, or 6 minutes in diameter! Can we compare it to the coruscations of the electric fluid in the aurora borealis? or to the more significant cone of the zodiacal light as we see it in spring or autumn? The latter, notwithstanding I have observed it to reach at least 90° from the sun, is yet of so little extent and brightness as possibly not to be perceived even by the inhabitants of Saturn or the Georgian planet, and must be utterly invisible at the remoteness of the nearest fixed star."

Herschel suggests that large nebulæ, like that in Orion, may possibly be composed of this luminous matter—an hypothesis which accounts, he says, "much better for it than clustering stars at a distance." This was a happy foresight of Herschel's into the existence of gaseous nebulæ, the truth of which has been fully proved in recent years by means of the spectroscope. The great nebula in Orion is now known to consist of glowing gas, as Herschel surmised. He further expresses his opinion that "planetary nebulæ" may also be composed of luminous gaseous matter and the spectroscope has confirmed the truth of this hypothesis also.

In the *Philosophical Transactions* for 1802, Herschel gives a further catalogue of 500 "new nebulæ, nebulous stars, planetary nebulæ, and clusters of stars." The numbers in each class are continued from the former catalogues, and bring the totals up to: First class, 228; second class, 907; third class, 978; fourth class, 78; fifth class, 52; sixth class, 42; seventh class, 67; and eighth, 88. In the preface to this catalogue he gives some interesting remarks on the various kinds of nebulæ. With reference to the globular clusters of stars he says there must clearly be a centre of attraction, either empty or occupied by a massive body, round which all the stars resolve. With reference to the nebulæ, properly so called, he considers that some, at least, may be clusters of stars rendered nebulous in appearance from the effects of immense distance, and that in some cases their light may possibly take nearly two millions of years to reach us! But this conclusion seems now improbable. Take a globular cluster like ω Centauri, and suppose that it contains 10,000 stars, each of the same size and intrinsic brightness of our sun, and that it is placed at such a distance that its light would take even one million of years to reach us. Its parallax would then be about $\frac{1}{307000}$ of a second of arc, which would imply a distance of about 63,000 million times the sun's distance from the earth! Placed at this enormous distance the sun would, I find, be reduced to a star of the 27th magnitude! and a cluster of 10,000 suns would shine as a star of the 17th magnitude, or a faint point of light barely visible in the great Lick telescope! But many of these globular clusters are comparatively bright objects, even in telescopes of moderate power, and a few, like ω Centauri, are easily visible to the naked eye. Herschel admits, however, that "milky nebulosity," such as that in the great nebula in Orion, is probably *not* due to clusters of stars. The spectroscope has now proved this conclusion to be correct.

In a paper in the *Philosophical Transactions* for 1811, relating to the "Construction of the Heavens," Herschel further considers the nebulæ. He says, "An equal scattering of the stars may be admitted in certain calculations; but when we examine the Milky Way, or the closely compressed clusters of stars, of which my catalogues have recorded so many instances, the supposed equality of scattering must be given up. We may also have surmised nebulæ to be no other than clusters of stars disguised by their very great distance, but a longer experience and better acquaintance with the nature of nebulæ will not allow a general admission of such a principle, although undoubtedly a cluster of stars may assume a nebulous appearance when it is too remote for us to discern the stars of which it is composed."[1] He gives in a table a list of 52 spots in the heavens, in which there is "diffused milky nebulosity" over a considerable area. These regions should be examined and photographed with our large modern telescopes.[2]

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[1] *Phil. Trans.*, 1811, p. 270.

[2] This has recently been done by Dr. Isaac Roberts, and in most of the cases he finds no nebulosity.

Herschel says, with reference to the great nebulæ in Orion, that "we can hardly have a doubt of it being the nearest of all the nebulæ in the heavens." And of "double nebulæ," or nebulæ having two centres of condensation, he suggests that in the course of ages they may divide and form two separate and distinct nebulæ close together. Dr. See has recently suggested that this may have been the origin of binary or revolving double stars.

With reference to what Herschel calls "cometic nebulæ," which show "a gradual and strong increase of brightness towards the centre of a nebulous object of a round figure," he says. Their great resemblance to telescopic comets, however, is very apt to suggest the idea that possibly such small comets as often visit our neighbourhood may be composed of nebulous matter, or may, in fact, be such highly condensed nebulæ."

In the *Philosophical Transactions* for 1814, Herschel continues his observations "relating to the sidereal part of the heavens and its connection with the nebulous part." He considers the apparent connection in many cases between stars and nebulæ, and shows that this connection is probably real and not merely apparent. From this he concludes that the stars were originally formed by the condensation of nebulous matter. This, of course, agrees with the nebular theory of Laplace.

In the *Philosophical Transactions* for 1818—his last paper on the subject—Herschel considers the probable distance of clusters of stars. Taking the power of his 20-feet Newtonian telescope to penetrate into space as 61·18 times that of the naked eye, which he assumes can see stars of the 12th order —that is 12 times the distance of stars like Capella and Vega—he concludes that several of the compressed clusters of stars lie at a distance of 734 times the distance of Capella or Vega. Some clusters he finds to be placed at the "900th order of distance," while in one case he concludes that the cluster lies at 950 times the distance of Capella or Vega. I find that if Capella or Vega were placed at 734 times their present distance—whatever that may be—they would be reduced in brightness to stars of about 14½ magnitude, and this would be about the faintest star visible in Herschel's telescope. Herschel's conclusions, of course, depend on the assumption that the stars of the clusters referred to are of the same size as the brighter stars, and that their faintness is due merely to their great distance from the earth. This assumption, however, cannot be considered as certainly true, for their faintness may possibly be due to small size as well as to great distance. Probably both causes combine to make them faint.

In the year 1825 Sir John Herschel, the famous son of Sir William Herschel, commenced a series of observations on the nebulæ in the northern hemisphere with a 20-feet reflector. The result of these observations are given in a catalogue published in the *Philosophical Transactions* for 1833. This catalogue contains 2306 nebulæ and clusters, of which 1781 were observed by Sir William Herschel and others, the remaining 525 being new. Among the latter, Sir John Herschel says there is "only one very conspicuous and large nebula, and only a very few entitled to rank in his (father's) first class, or among the 'bright nebulæ.' By far the greater proportion of them are objects of the last degree of faintness, only to be seen with much attention and in a good state of the atmosphere and instrument." He gives a series of plates with some beautiful drawings of the various kinds of nebulæ. Some of the forms depicted are very curious. One of them is spindle-shaped with a vacuity in the middle. It looks like a circular ring seen very obliquely, and reminds one of Saturn's ring, if we imagine the planet removed. This remarkable object is No. 19 of Sir William Herschel's Fifth Class, and is described by Sir John Herschel as "an extraordinary ray 3′ or 4′ long; 40″ broad; very large; very much elongated; pretty faint; has a chink or dark division in the middle and two stars. Position with meridian 21°·2. A wonderful object." In the drawing the stars mentioned are placed at each end of the central opening, and certainly look as if they were connected with the nebula. A photograph, taken by Dr. Roberts in December, 1891, agrees well with the above description. He says, "The descriptions given by the observers just cited will also apply to the photograph, and the suggestion by Sir John Herschel that the nebula is a thin, flat ring of enormous dimensions, seen very obliquely, receives strong confirmation."

With reference to the well-known "dumb-bell nebula," of which he gives a drawing, Sir John Herschel says, "The outline is filled up elliptically with a faint nebulosity, as in figure, which, I think, leaves ansæ, as if inclined to form a ring." This view of its construction is shown to be correct by a photograph taken by Dr. Roberts in the year 1888, which shows that the nebula is really a globe surrounded by a darker ring. Dr. Roberts says, "The nebula is probably a globular mass of nebulous matter which is undergoing the process of condensation into stars, and the faint protrusions of nebulosity on the *south following* and *north preceding* ends are the projections of a broad ring of nebulosity which surrounds the globular mass. This ring, not being sufficiently dense to obscure the light of the central region of the globular mass is dense enough to obscure those parts of it that are hidden by the increased thickness of the nebulosity, thus producing the 'dumb-bell' appearance."

Another curious object is a small round nebula surrounding a triple star, the stars forming an equilateral triangle, of which the sides are about 4″ in length, and the stars of the 11th, 12th, and 14th magnitude. "The nebula surrounds the star like an atmosphere." This is No. 261 of Sir William Herschel's First Class, and lies a little south—following the star ϕ Aurigæ. Webb saw four stars with a $9\frac{1}{3}$-inch speculum in 1873 and 1876; D'Arrest five stars; Lord Rosse saw six stars, and found the nebula oval, with branches.

Another interesting object is one discovered by Sir John Herschel, of which he gives a drawing, and describes it as "a most remarkable phenomenon. A very large space, 20 or 30 minutes broad in polar distance, and 1 minute or 2 minutes in right ascension full of nebula and stars mixed. The nebula is decidedly attached to the stars, and as decidedly not stellar. It forms irregular lacework marked out by stars, but some parts are decidedly nebulous, wherein no stars can be seen. A figure represents general character, but not the minute details of this object, which would be extremely difficult to give with any degree of fidelity." It lies about $3\frac{1}{2}°$ preceding the star ζ Cygni.

In the year 1834 Sir John Herschel went to the Cape of Good Hope to observe the southern heavens, and in an interesting and classical work, known as the "Cape Observations," he gives a catalogue of 1707 nebulæ, most of which are south of the equator. Of these, 89 are identical with objects in his first catalogue, mentioned above, and 135 are included in Sir William Herschel's catalogues. The instrument used by Sir John Herschel in these observations was a reflector of the same size as that used by Sir William Herschel.[1] From this southern catalogue of Sir John Herschel's I select the following interesting objects, which, so far as I know, have not been described in popular books on astronomy.

h. 2345. Nebula about 7° south of the star β Ceti. It is described by Sir John Herschel as "very, very bright; exceedingly large; very much elongated; 30 minutes long, 3 or 4 minutes broad; has several stars in it; gradually much brighter in the middle to a centre elongated like the nebula itself. The nebula is somewhat streaky and knotty in its constitution, and may perhaps be resolvable;" and in a second observation he says, "A superb object. The light is somewhat streaky, but I see no stars in it, but four large and one very small one, and these seem not to belong to it, there being many near." This nebula is No. 1 of Sir William Herschel's Fifth Class, and was discovered by Miss Caroline Herschel in 1783.

h. 2878. A nebula situated near the northern edge of the Nubecula Major, or "greater Magellanic Cloud." Sir John Herschel describes it as

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[1] See next chapter.

"very bright; very large; oval; very gradually pretty much brighter in the middle; a beautiful nebula; it has very much resemblance to the Nubecula Major itself as seen with the naked eye, but is far brighter and more impressive in its general aspect, as if the nubecula were at least doubled in intensity. . . . And who can say whether in this object, magnified and analyzed by telescopes infinitely superior to what we now possess, there may not exist all the complexity of detail that the nubecula itself presents to our examination."

h. 3315. A little north preceding the great nebula in Argo (which surrounds the variable star η Argûs). Sir John Herschel describes it as "a glorious cluster of immense magnitude, being at least two fields in extent every way. The stars are 8, 9, 10, and 11 magnitude, but chiefly 10 magnitude, of which there must be at least 200. It is the most brilliant object of the kind I have ever seen." In another observation he says, "A very large round, loosely scattered cluster of stars 8 . . . 12 m. stars, which fills two or three fields. A fine bright object." And in a third observation he says, "A superb cluster, which has several elegant double stars, and many orange-coloured ones."

As in his first catalogue, he gives beautifully executed drawings of some of the nebulæ he observed. Some of the forms shown are very curious and interesting, and several are very similar in shape to objects observed in the northern hemisphere. He also gives elaborate drawings of the great nebula in Orion, the nebula round η Argûs, and the various objects contained in the Nubecula Major. His detailed descriptions of these wonderful objects are very valuable for comparison with photographs which have been taken or will be taken in the future. He also gives a catalogue of the objects visible in the Nubecula Major and Nubecula Minor, so that any future change in the brightness or position of any of these objects can be easily detected.

Many new nebulæ have of course been discovered since the days of the Herschels, but these are, for the most part, exceedingly faint objects, and we may say that the heavens were thoroughly explored by the Herschels so far as the power of their telescopes would permit. They were excellent observers, and no greater astronomers ever lived.

XIX

A Chapter in the History of Astronomy

IN the year 1825 the famous astronomer Sir John Herschel commenced a re-examination of the nebulæ and clusters of stars discovered by his illustrious father, Sir William Herschel. This work was carried on for about eight years, and the results were presented to the Royal Society, and were published in their *Philosophical Transactions* in the form of a catalogue. This work contained observations of 2306 nebulæ and clusters of stars, of which 525 were new. In addition to the nebulæ and clusters, many double stars were also observed, and the observations of these were published in the *Transactions of the Royal Astronomical Society.* All these observations were made with the aid of a reflecting telescope of 18¼ inches clear aperture and 20 feet focal length, and the practice thus acquired, combined with the interest of the subject, induced Sir John Herschel "to attempt the completion of a survey of the whole surface of the heavens, and

Jh Herschel

for this purpose to transport into the other hemisphere the same instrument which had been employed in this, so as to give a unity to the results of both portions of the survey, and to render them comparable with each other."

At Cape Town 1833-34

In pursuance of this scheme, the indefatigable astronomer packed up his large reflector and also an equatorically mounted achromatic telescope of 5 inches aperture and 7 feet focal length, made by Tully, with other apparatus, and sailed with his family from Portsmouth on board the East India Company's ship *Mount Stewart Elphinstone*, on November 13, 1833. After a pleasant voyage he landed safely with his instruments at Table Bay, Cape of Good Hope, on January 16, 1834. He then looked out for a residence in a suitable locality, and soon found one at a place called Feldhuysen, or Feldhausen, about 6 miles from Cape Town, near the base of Table Mountain. In this favourable position, sheltered on one side by Table Mountain, and on the other by oak and fir trees, a building was erected for the equatorial instrument, and on May 2, 1834, "a series of micrometrical measures of southern double stars was commenced by the measurement of α Centauri, the chief among them." At a short distance from this building the large reflector was erected in the open air. The exact position of this astronomical station was in south latitude 33° 58′ 56″·55, longitude $22^h\ 46^m\ 9^s{\cdot}11$ from Greenwich. Its height above the mean sea-level of Table Bay was about 142 feet.

The reflector was provided with three mirrors, one made by Sir William Herschel, and used by him in his 20-feet "sweeps" of the northern heavens, and the other two constructed by Sir John Herschel himself. With this instrument observations were made "in search of new objects" in "sweeps" of three degrees in breadth in polar distance, on clear moonless nights. The months from May to October, the winter of the southern hemisphere, and especially June and July, proved most suitable for observation, and nights after heavy rain were found to be the best for the purpose.

At this favourably situated station the distinguished astronomer carried on his observations during the years 1834 to 1838, and a short account of the results he obtained may prove of interest to the reader.

The first portion of these results is contained in a splendid work which was published in 1847, at the expense of the Duke of Northumberland, and consists of a catalogue of nebulæ and clusters of stars observed in "sweeps" with the 20-inch reflector. The positions of these interesting objects are carefully noted, and a short description of each is given. In addition to the catalogue, which contains 1707 objects, separate drawings were made of the most remarkable and interesting nebulæ and clusters. These include drawings of the great nebula in Orion; the "trifid" nebula; the looped nebula, 30 Doradus; the nebula surrounding the variable star η Argûs; the clusters ω Centauri and 47 Toncani; that surrounding κ Crucis, and other remarkable and interesting objects. These drawings are beautifully executed in black on a white ground, and exhibit some of the most striking and extraordinary forms visible in the southern heavens. An elaborate drawing is also given of the larger "Magellanic cloud," showing the brighter clusters and nebulæ, and the stars down to the 10th magnitude included in this wonderful object. This drawing will be of great use for comparison with future photographs of this marvellous cluster, which contains all forms of sidereal objects from stars to irresolvable nebulæ. In addition to the drawing, a catalogue is given of the objects in the Nubecula Major and Minor, as the "Magellanic clouds" are termed by astronomers. The beautiful drawing of the great nebula in Orion, given by Sir John Herschel, agrees fairly well in its principal details with modern photographs; but owing to the long exposure required to bring out the fainter portions of the nebula, the brighter portions are, in the photographs, always overexposed, and render a comparison with the drawing a matter of some difficulty.

Following the catalogue of nebulæ is a catalogue of double stars observed with the 20-feet reflector. This list includes 2102 objects, and is followed by a list of micrometrical measures of 417 doubles made with the 7-feet equatorial. To these measures are added a series of notes describing the appearance and character of the various objects measured. Some of these measures have been found very useful in calculating the orbits of some of the southern binary or revolving double stars, the angular motion of some of these interesting objects having been considerable since the date of Sir John Herschel's observations. These measures of double stars are followed by notes on the most remarkable of these objects. They include very interesting observations of the famous binary star γ Virginis, and an investigation of the orbit of this remarkable stellar system. The period of revolution found by Sir John Herschel (182 years) agrees well with the best recent determinations.

Another work undertaken by Sir John Herschel was the determination of the relative brilliancy of the brighter stars in the southern hemisphere. These determinations were chiefly made by observation with the naked eye, without the aid of any instrument. A form of photometer was tried, but the results obtained with it did not prove very satisfactory. The naked eye observations were made by the method of sequences—a method which consists in arranging the stars in lists in the order of brightness, combining these sequences, and then reducing the observations to a uniform scale. Sir John Herschel says, "I am disposed to rely mainly for the formation of a real scale of magnitudes on comparisons made by the unassisted judgment of the naked eye," and although photometers have been in recent years most successfully used for this purpose, still, for small differences of brightness between neighbouring stars, the eye alone could, with experienced observers, probably hold its own against any photometer. The work of Sir John Herschel, like the whole of his work at the Cape, was carried out in continuation of the work done by his illustrious father, Sir William Herschel, in the northern hemisphere. The elder Herschel's results will be found in the *Philosophical Transactions* of the Royal Society for the years 1796, 1797, and 1799, and form a valuable record in connection with suggested variability in any of the brighter stars. Sir John Herschel gives his sequences in detail, and the reduced magnitudes of the stars observed. In his reduced list he gives the following as the twelve brightest stars in order of magnitude: Sirius, Canopus, α Centauri, Arcturus, Capella, α Lyræ (Vega), Rigel Procyon, α Eridani, α Orionis, Aldebaran, and β Centauri.

While at the Cape, Sir John Herschel made a careful examination of the "general appearance and telescopic constitution of the Milky Way in the southern hemisphere," and his results, which are very interesting, form a valuable contribution to our knowledge of this wonderful zone. From the telescopic aspect of the Galaxy in this region, he concludes that "it consists of portions differing exceedingly in distance, but brought by the effect of projection into the same, or nearly the same, visual line; in particular, that at the anterior edge of what we have called the main stream, we see foreshortened a vast and illimitable area scattered over with discontinuous masses, and aggregates of stars in the manner of the cumuli of a mackerel sky, rather than a stratum of regular thickness and homogenous formation; and that in the enclosed spaces insulated from the rest of the heavens by the preceding and following streams, and the 'bridges' above spoken of as connecting them (as, for instance, in that which includes λ Scorpii), we are, in fact, looking out into space through vast chimney-form or tubular vacancies, whose terminations are rendered nebulous by the effect of their exceeding distance, and, at the same time, are brought by that of perspection to constitute the interior borders of apparent vacuities." Recent observations and photographs, however, now render this conclusion more than doubtful, and the weight of evidence seems in favour of the hypothesis, that the Milky Way is in reality what it seems to be, namely, a system of a roughly circular section, the most distant parts being, comparatively, not much farther from us than the nearest, and that the differences in luminosity are due rather to differences in aggregation, and in the absolute sizes of the component stars, than to difference of distance.

While Sir John Herschel was at the Cape the famous comet of Halley returned to the sun's vicinity. It was carefully observed by the great astronomer, and he gives full details of his observations in the work above referred to, and some beautiful drawings of the appearance presented by the nucleus or head. He also made observations of the satellites of Saturn, and the solar spots which are interesting for comparison with modern observations.

After Sir John Herschel's departure from the Cape an obelisk was erected by some friends to mark the site occupied by the large reflector. This column bears the following inscription: "Here stood, from 1834 to 1838, the reflecting telescope of Sir John Herschel, Baronet; who, during a residence of four years in this colony, contributed as largely, by his benevolent exertions, to the cause of education and humanity as by his eminent talents to the discovery of scientific truth."

XX

Messier's Nebulæ

IN the year 1771, Messier, the famous discoverer of comets, published a catalogue of 68 nebulæ in the "Memoirs of the French Academy of Science." In the years 1781, 1782 this list was republished in the *Connaissance des Temps*, and 35 other nebulæ were added, thus bringing the total up to 103 nebulæ. Most of these nebulæ have been carefully re-observed since Messier's time, and some of them have proved to be most wonderful and interesting objects. As these observations and descriptions are scattered through various publications, some of them almost inaccessible to the general reader, I have compiled the following list, with short descriptions of the appearance and character of each nebula. The positions are given for 1900·0. There are a few of Messier's nebulæ, of which I have been unable to find any account. These are Nos. 40, 45, 48, and 102.

Messier 1: R.A. 5^h $28^m{\cdot}5$, N. 21° 57′. This is the famous "Crab nebula" in Taurus. It lies about

1° north preceding the star ζ Tauri. It was first seen by Bevis in 1731. It was again seen by Messier in 1758, while observing the comet of that year, and its re-discovery induced him to form his catalogue of nebulæ, to help observers in distinguishing these objects from comets. Sir John Herschel thought it was a cluster of stars at a distance "of about the 980th order," that is 980 times the distance of Capella or Vega. Lord Rosse's great telescope was supposed to have resolved it into stars, but photographs, taken by Dr. Isaac Roberts in 1892 and 1896, show a very nebulous appearance, and but little of the "crab-like" form depicted in Lord Rosse's drawing.

M. 2 : $21^h\ 28^m{\cdot}3$, S. 1° 15′. In Aquarius, about 5° north of the star β Aquarii. A globular cluster of 5′ or 6′ in diameter. Sir John Herschel compared it to a heap of white sand; and Admiral Smyth says, "This magnificent ball of stars condenses to the centre, and presents so fine a spherical form that imagination cannot but picture the inconceivable brilliance of their visible heavens to its animated myriads." But that each of these points of light should have planets revolving round it seems very doubtful. Sir William Herschel, with his 40-feet telescope, could see the individual stars even in the centre of the cluster. A photograph by Dr. Roberts, taken in 1891, shows the centre of the cluster involved in dense nebulosity, and he thinks that it was probably evolved from a spiral nebula. The stars composing the cluster are very faint, probably not brighter than the 15th magnitude. Seen as a star, it was measured 7·69 magnitude at the Harvard Observatory, U.S.A. Assuming these magnitudes as correct, I find that the cluster contains about 800 stars.

M. 3: 13^{h} 37^{m}·6, N. 28° 53′. A fine globular cluster in the constellation Canes Venatici, about 12° north preceding Arcturus. Messier, who discovered it in 1764, described it as "a nebula without a star, brilliant and round." Sir William Herschel, with his 20-feet reflector, found it "a beautiful cluster of stars 5′ or 6″ in diameter." Sir John Herschel describes it as very large and bright, with stars about 11th to 15th magnitude. Smyth called it "a noble object," and thought it contained "not less than 1000 small stars." Lord Rosse saw it as a cluster blazing in the centre with rays of stars running out from it on all sides. A photograph by Dr. Roberts, in May, 1891, "confirms the general descriptions" of previous observers. No less than 132 variable stars have been detected among the outliers of this cluster!

M. 4: 16^{h} 17^{m}·5, S. 26° 17′. A large but rather faint object, about 1½° preceding Antares. Discovered by Messier in 1763. In 1783 Sir William Herschel resolved it into stars. Smyth describes it as "a compressed mass of small stars . . . with outliers, and a few small stellar companions in the field."

M. 5 : 15^{h} 13^{m}·5, N. 2° 27′. A globular cluster of stars of 11th to 15th magnitudes, lying closely north preceding the 5th magnitude star 5 Serpentis. Messier was "certain that it contained no star!" Sir William Herschel resolved it, and estimated the number of stars at 200, but it probably contains many more. Smyth describes it as "a noble mass, refreshing to the senses after sweeping for faint objects." A photograph by Dr. Roberts shows stars to 15th magnitude "with dense nebulosity about the centre." No less than 85 variable stars have been detected among the outliers of this cluster.

M. 6 : 17^{h} 33^{m}, S. 32° 10′. In Scorpio. Sir John Herschel calls it "a fine large discrete cluster of stars, 10, 11; one star is 7^{m}; one is 7·8. Fills field." From the position given by Sir John Herschel for the nebula Dunlop, 612, it should be in the same low-power field with M. 6; but observing in the Punjab I could only see *one* cluster near the place, with stars in "zigzag lines," which agree with Herschel's description of Dunlop's nebula.

M. 7 : 17^{h} 44^{m}, S. 30° 39′. Sir John Herschel describes it as "A highly condensed nebulous mass, 3′ diameter, on an irregular round nebula; pretty much brighter in the middle; resolvable."

M. 8 : 17^{h} 57^{m}·6, S. 24° 22′. A very fine object in the Milky Way in Sagittarius. Visible to the naked eye. A beautiful drawing of it, showing nebulous streaks and loops, is given by Sir John Herschel in his *Cape Observations*, and he calls it "a superb nebula." I found it plainly visible to the naked eye in the Punjab, and a glorious object even with a 3-inch refractor. It has been photographed by Dr. Roberts (*Knowledge*, June, 1900). Secchi found the spectrum that of a gaseous nebula.

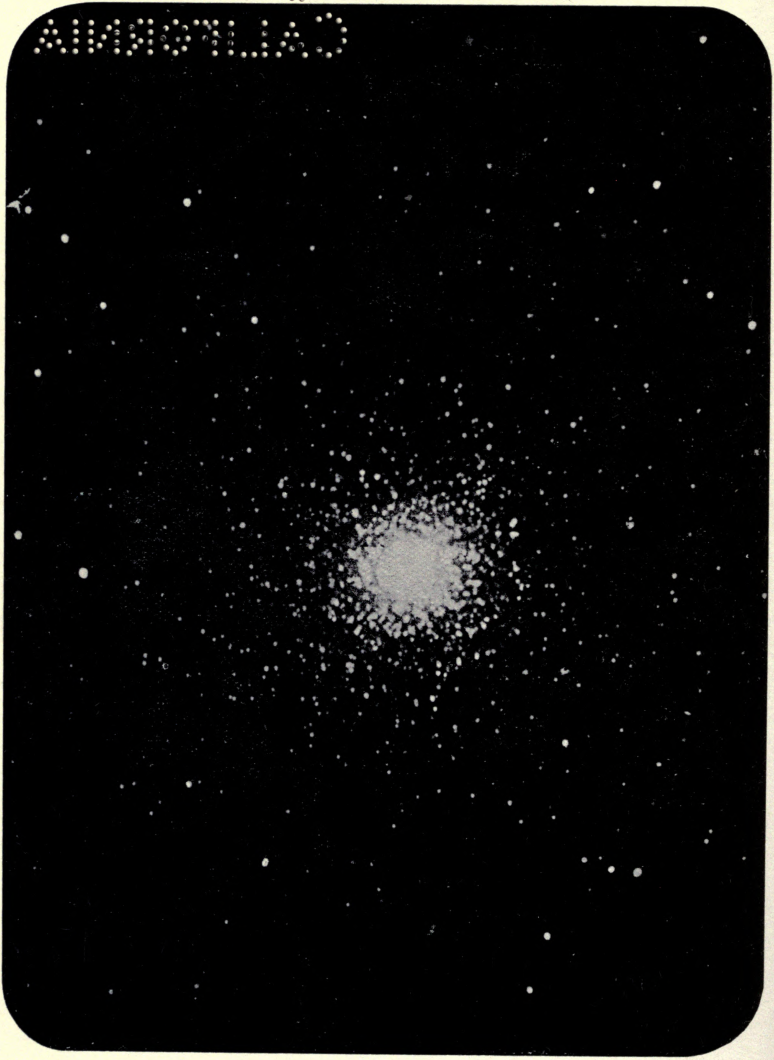
M. 9: $17^h\ 13^m{\cdot}3$, S. 18° 25′. Between η and 58 Ophiuchi; nearer to η. Discovered in 1764 by Messier, who described it as a nebula "unaccompanied by any star;" but it was resolved into stars by Sir William Herschel in 1784 with his 20-feet reflector. Sir John Herschel, at the Cape, found it about 4′ in diameter, and "resolved into stars of the 14th magnitude." Smyth says, "This fine object is composed of a myriad of minute stars, clustering into a blaze in the centre, and wonderfully aggregated, with numerous outliers seen by glimpses."

M. 10: $16^h\ 51^m{\cdot}9$, S. 3° 57′. About 10° east of the stars δ and ϵ Ophiuchi. Sir John Herschel describes it as "a fine large cluster . . . diameter 5′, with stragglers, several of which are of larger size to about 12′; all resolved into stars 11–15 magnitude; very compressed." A photograph by Dr. Roberts in June, 1891, shows the cluster "nearly free from nebulosity."

M. 11: $18^h\ 45^m{\cdot}7$, S. 6° 23′. In the so-called "Shield of Sobieski," which forms the southern portion of Aquila. Discovered by Kirch in 1681. Sir William Herschel saw stars of about 11th magnitude divided into 5 or 6 groups, and he found it just visible to the naked eye. Sir John Herschel called it round and rich, with stars 9–11 magnitude. Smyth compared it to "a flight of wild ducks," and says it "is a gathering of minute stars with a prominent 8th magnitude star in the middle and two following." A photograph by Dr. Roberts agrees well with the descriptions, and shows that the cluster is free from nebulosity.

M. 12: $16^h\ 42^m{\cdot}0$, S. 1° 48′. Between δ and 41 Ophiuchi. It was discovered by Messier in 1764, and described by him as "a round nebula, unaccompanied by any star." Sir John Herschel found it resolvable into stars of 10th magnitude. Smyth called it "a fine rich globular cluster, with a *cortège* of bright stars and many minute straggling outliers." A photograph taken by Dr. Roberts in June, 1892, shows the stars visible to the centre with "a trace of nebulosity." It should be stated, however, that Professor Barnard finds that there is no trace of nebulosity in any of the great globular clusters, as seen in the great Yerkes telescope.

M. 13: $16^h\ 38^m{\cdot}1$, N. 36° 37′. This is the famous globular cluster in Hercules, between η and ζ, and considered to be one of the finest of its class. It was discovered by Halley in 1714. Messier, who observed it with a 4-feet Newtonian reflector and



THE GREAT GLOBULAR CLUSTER IN HERCULES (M. 13).

From a Photograph by W. E. Wilson, F.R.S.

power of 60, was "assured that it contained no star!" Sir William Herschel described it as "a most beautiful cluster of stars, exceedingly compressed in the middle and very rich." He estimated the number of stars at 14,000. Sir John Herschel saw thousands of stars in it. Smyth calls it "a superb object," and Dr. Nichol remarked that "Perhaps no one ever saw it for the first time through a telescope without uttering a shout of wonder." Lord Rosse found 3 dark streaks, or lanes, which were also seen by Buffham. Photographs taken by Dr. Roberts in 1887 and 1895, show the dark lanes seen by Lord Rosse, and he thinks it was probably evolved from a spiral nebula. From a photograph taken in America by Mr. H. K. Palmer, with an exposure of two hours, he finds the number of stars to be 5482, of which 1016 are "bright," and 4466 "faint." The dark lanes are also clearly visible in Palmer's photograph.

M. 14: $17^{h}\ 32^{m}{\cdot}3$, S. 3° 11′. Between τ and 41 Ophiuchi. Sir John Herschel found it "a most beautiful and delicate globular cluster; not very bright, but of the finest star-dust; all well resolved . . . excessively rich. All the stars equal 15 or 16 m." Lord Rosse found the stars very close and very small. A photograph by Dr. Roberts in August, 1897, shows "curves and lines of stars radiating in all directions outwards from the dense cluster . . . as well as vacancies, within the nebulous centre."

M. 15: $21^{h}\,25^{m}{\cdot}1$, N. 11° 43′. A globular cluster in Pegasus in a comparatively vacant space about 4° north following δ Equulei. It was discovered in 1745 by Miraldi, who thought it contained "many stars." Sir John Herschel estimated the component stars about 15th magnitude. Lord Rosse described it as a globular cluster with bright and faint stars. A photograph by Dr. Roberts "confirms the general descriptions," and shows the stars arranged in "curves, lines, and patterns," and the centre nebulous.

M. 16: $18^{h}\,13^{m}{\cdot}2$, S. 13° 49′. South of "Sobieski's Shield." Sir John Herschel described it as a cluster containing at least 100 stars, and Smyth called it "A scattered and fine large cluster." But a photograph by Dr. Roberts in August, 1897, shows that it is really "a large bright *nebula*, with a cluster apparently involved in it."

M. 17: $18^{h}\,15^{m}{\cdot}0$, S. 16° 14′. This is the so-called "horse-shoe," or "Omega" nebula. It lies about $2\frac{1}{2}^{\circ}$ south of Messier 16. It was described by Sir John Herschel as a magnificent object, bright, and very large. It was also described and drawn by Lord Rosse, Lassell, Holden, and Trouvelot. Smyth gives a drawing of it which very much resembles a horse-shoe, but this form is nearly lost in a photograph by Dr. Roberts in August, 1893. Sir William Huggins finds the spectrum gaseous.

M. 18: $18^{h}\,14^{m}{\cdot}1$, S. 17° 10′. About one degree south of M. 17. Webb says, "Glorious field in a very rich vicinity; south lies a region of surpassing splendour."

M. 19: $16^h\ 56^m{\cdot}4$, S. 26° 7′. Between 39 Ophiuchi and Antares, nearer the former. Sir William Herschel resolved it into stars. Sir John Herschel describes it as "superb. A globular cluster; very bright; round; diameter 10′; resolved into stars 14th, 15th, 16th magnitude." Smyth called it "A fine insulated globular cluster of small and very compressed stars," and he says it "is near a large opening, or hole, about 4° broad, in the Scorpion's body, which Sir William Herschel found almost destitute of stars."

M. 20: $17^h\ 56^m{\cdot}3$, S. 23° 2′. This is the well-known "Trifid nebula," which lies closely north of the star, 4 Sagittarii. A very curious object, with three dark lanes radiating from the centre. It has been well drawn by Sir John Herschel and Trouvelot, and it was photographed at the Lick Observatory with the Crossley reflector.[1] Although it has a very nebulous appearance, the spectrum seems to be *not* gaseous.

M. 21: $17^h\ 58^m{\cdot}7$, S. 22° 30′. Between μ and 4 Sagittarii and a little north following the "Trifid nebula" (M. 20). Smyth describes it as "A coarse cluster of telescopic stars in a rich gathering galaxy region"

M. 22: $18^h\ 30^m{\cdot}3$, S. 23° 59′. About midway

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[1] *Astrophysical Journal*, May, 1900.

between μ and σ Sagittarii. It seems to have been seen by Hevelius before 1665, and it was drawn by Le Gentil in 1747. Messier, who observed it in 1764, thought that it contained no stars! Sir John Herschel describes it as "a globular cluster, very bright; very large; very much compressed, 7′ diameter. The stars are of two magnitudes, 15–16 magnitude and 12 magnitude; and what is very remarkable, the largest of these latter are visibly reddish." And in another observation he says, "Consists of stars of two sizes, 11 and 15, with none intermediate, as if it consisted of 2 layers, or one shell over another. A noble object." Webb found it "very interesting from visibility of components 10 and 11 magnitude,[1] which makes it a valuable object for common telescopes, and a clue to the structure of many more distant or difficult nebulæ." Observing with 3-inch refractor in the Punjab, the present writer found the larger stars well seen; but the greater portion of the cluster is nebulous with a telescope of this size.

M. 23: $17^h\ 51^m\!\cdot\!0$, S. 19° 0′. Smyth describes it as "A loose cluster . . . an elegant sprinkling of telescopic stars over the whole field, under a moderate magnifying power." Webb says, "Grand low-power field."

M. 24: $18^h\ 12^m\!\cdot\!6$, S. 18° 27′.—About 3° north of μ Sagittarii. Sir John Herschel describes it as

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[1] Probably Sir John Herschel's *brighter* components.

THE DUMB-BELL NEBULA.

From a Photograph by W. E. Wilson, F.R.S.

pretty large and very rich, with stars of 11–20 magnitude. Lord Rosse saw some unresolved nebulous light in it, but a photograph by Dr. Roberts, taken in February, 1894, shows the stars free from nebulosity. On this photograph the streams of stars surrounding the centre seem to be arranged in spirals, and strongly suggest that the cluster has been evolved from a spiral nebula.

M. 25: 18^{h} 24^{m}·1, S. 19° 2′. Smyth describes it as "a loose cluster of large and small stars in the Galaxy." Closely south following this nebula is the short-period variable star V Sagittarii, which varies from 7·0 to 8·3 magnitude with a period of about $6\frac{3}{4}$ days. It was discovered by Schmidt in 1866.

M. 26: 18^{h} 39^{m}·7, S. 9° 29′. A little south, following the star 2 Aquilæ in "Sobieski's Shield." Sir John Herschel describes it as large and pretty rich; stars 12th to 15th magnitude. Smyth calls it "a small and coarse, but bright cluster of stars," and this is confirmed by a photograph taken by Dr. Roberts in August, 1892.

M. 27: 19^{h} 55^{m}·3, N. 22° 27′. The well-known "Dumb-bell" nebula. It lies a little south of the star 14 Vulpeculæ. It has been drawn by Sir John Herschel, d'Arrest, Lord Rosse, and Lassell. At one time Lord Rosse thought that it might be resolvable into stars, but Huggins found a gaseous spectrum. Photographs by Dr. Roberts and Dr. Wilson show it as a globular mass surrounded by a broad and darker ring which gives it the dumb-bell appearance. From recent photographs taken by Schaeberle he finds that "this object is a great *counter* clock-wire spiral, at least half a degree in diameter, the well-known nebula occupying the central area."[1]

M. 28: $18^h\ 18^m{\cdot}4$, S. 24° 55′. A globular cluster. It lies about 1° north preceding the star λ Sagittarii. Messier described it as a nebula without a star, but Sir William Herschel resolved it, and Sir John Herschel describes it as "very bright; round; very much compressed . . . resolved into stars 14 . . . 16 m.; a fine object." This nebula with Messier's numbers 8, 16, 17, 18, 20, 21, 22, 23, 24, and 25, all lie in a comparatively small area of the sky surrounding the 4th magnitude star μ Sagittarii.

M. 29: $20^h\ 20^m{\cdot}5$, N. 38° 11′. About 2° south of γ Cygni. Smyth describes it as "a neat but small cluster of stars."

M. 30: $21^h\ 34^m{\cdot}7$, S. 23° 38′. Closely north preceding the 5th magnitude star 41 Capricorni. There is an 8th magnitude star close to it. It was resolved into stars by Sir William Herschel in 1783, and Sir John Herschel describes it as "A globular cluster; bright, 4′ long by 3′ broad; all resolved into stars 16 m., besides a few 12 m." Lord Rosse found a spiral arrangement of the stars.

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[1] *Astronomical Journal*, No. 547, September 30, 1903.

M. 31: $0^h\ 37^m\cdot3$, N. 40° 43′. "The great nebula in Andromeda." Plainly visible to the naked eye, a little west of the star ν Andromedæ, and quite a conspicuous object even in a binocular field-glass. Al-Sufi refers to it as a familiar object in his time (10th century). This magnificent nebula has been frequently drawn, and has been so often described in astronomical books that a detailed description is unnecessary here. Photographs by Dr. Roberts and others show its real character. At first it was supposed to be annular, but Dr. Roberts says, "That the nebula is a left-hand spiral, and not annular as I at first supposed, cannot now be questioned; for the convolutions can be traced up to the nucleus, which resembles a small bright star at the centre of the dense surrounding nebulosity; but, notwithstanding its density, the divisions between the convolutions are plainly visible on negatives which have had a proper degree of exposure;" and he thinks that "these photographs throw a strong light on the probable truth of the *Nebular Hypothesis*, for they show what appears to be the progressive evolution of a gigantic stellar system." He finds its apparent diameter about $2\frac{1}{3}$°. It seems to be not gaseous, as Huggins finds a continuous spectrum. A small "new," or "temporary star" suddenly appeared near the nucleus in August, 1885. It had faded to the 16th magnitude in February, 1890.

M. 32 : $0^h\ 37^m$, N. 40° 18′. A small bright round nebula a little south of the nucleus of the great nebula in Andromedæ (M. 31). It was discovered by Le Gentil in 1749. It is said to have been resolved into stars by Lord Rosse's 3-feet telescope. Its spectrum is similar to that of the great nebula.

M. 33 : $1^h\ 28^m{\cdot}2$, N. 30° 9′. Between β Andromedæ and α Arietis, nearer to β Andromedæ. It was described by Sir John Herschel as a remarkable object, extremely large, round and very rich, and resolvable into stars; but a photograph by Dr. Roberts, in November, 1895, shows it to be really a spiral nebula. There is a nucleus of "dense nebulosity," with about 20 stars involved, and the other parts of the nebula contain hundreds of faint nebulous stars of about 16th or 17th magnitude. It is of considerable apparent size, measuring about 1° long by $\frac{1}{2}$° in width.

M. 34 : $2^h\ 35^m{\cdot}6$, N. 42° 21′. About 5° North preceding Algol (β Persei). Just visible to the naked eye in a clear sky. Messier called it "a mass of small stars." Sir John Herschel described it as bright, very large, and but little compressed, with scattered stars of the 9th magnitude. Smyth says "it is a scattered but elegant group of stars from the 18th to the 13th degree of brightness on a dark ground, and several of them form close pairs." A photograph taken by Dr. Roberts in December, 1892, shows a loose cluster of stars down to the 15th magnitude; but it is not very

THE SPIRAL NEBULA, 33 MESSIER TRIANGULI.

From a Photograph by W. E. Wilson, F.R.S.

rich, and the stars can be easily counted. On the print the densest part of the cluster does not apparently contain more than 100 stars. But there may be more on the original negative.

M. 35: 6^{h} 2^{m}·7, N. 24° 21′. A little north preceding the star η Geminorum. Just visible to the naked eye. Sir John Herschel described it as a very large, rich cluster, with stars 9th to 16th magnitude. Lord Rosse called it "magnificent," and he counted 300 stars in a field of 26 minutes of arc, or less than the moon's apparent diameter. Lassell described it as a marvellously "striking object." On a photograph taken in February, 1893, by Dr. Roberts, he counted 620 stars in a field of 26 minutes, or more than double the number seen by Lord Rosse. But a glance at the photographs shows that it is not nearly so rich in stars as the globular clusters.

M. 36: 5^{h} 29^{m}·7, N. 34° 4′. About 2° following the star ϕ Aurigæ. Sir John Herschel describes it as bright, very large, and very rich, with stars of the 9th and 11th magnitudes. Lord Rosse called it a coarse cluster. Smyth says "a splendid cluster . . . a rich though open splash of stars from the 8th to the 14th magnitude, with numerous outliers." But these descriptions are somewhat misleading, as in a photograph taken by Dr. Roberts in February, 1893, the stars seem comparatively few in number, and do not much exceed 100, at least on the print. Compared with the following cluster—M. 37 in the same constellation—M. 36 is comparatively poor.

M. 37: $5^{\text{h}}\ 45^{\text{m}}{\cdot}7$, N. 32° 31′. About midway between ϕ and κ Aurigæ. Sir John Herschel describes it as a rich cluster with large and small stars. Smyth calls it "a magnificent object, the whole field being strewed as it were with sparkling gold-dust; and the group is resolvable into about 500 stars from the 10th to the 14th magnitude, besides the outliers." This description is confirmed by a photograph taken by Dr. Roberts in February, 1893, in which the stars are shown down to about the 16th magnitude. The surrounding region is pretty rich in stars.

M. 38: $5^{\text{h}}\ 22^{\text{m}}{\cdot}0$, N. 35° 45′. About $1\frac{1}{2}$° north of ϕ Aurigæ. Smyth describes it as "A rich cluster of minute stars. . . . It is an oblique cross with a pair of large stars in each arm and a conspicuous single one in the centre." Webb says, "Glorious neighbourhood."

M. 39: $21^{\text{h}}\ 29^{\text{m}}$, N. 47° 59′. About 3° south preceding π' Cygni. Smyth describes it as "A loose cluster, or rather splashy galaxy field of stars, in a very rich vicinity."

M. 41: $6^{\text{h}}\ 42^{\text{m}}{\cdot}7$, S. 20° 38′. About 4° south of Sirius. Just visible to the naked eye. It is referred to by Aristotle in his "Meteorologies" as a star "with a tail." Messier described it as a mass of small stars. Smyth calls it "a scattered cluster . . . divided into five groups;" and Webb

THE STAR CLUSTER 38 MESSIER IN AURIGA.

From the original Photograph taken by MM. Henry, at the Paris Observatory, January 28, 1887.

says, "Superb group. . . . Larger stars in curves with ruddy star near centre," which Espin suspects to be variable in light.

M. 42: $5^{h}\ 30^{m}{\cdot}4$, S. 5° 27′. This is "the great nebula in Orion," which has been so fully described, drawn, and photographed that a detailed account is unnecessary here.

M. 43. This is the small nebula closely north of the great nebula in Orion, M. 42.

M. 44: $8^{h}\ 34^{m}{\cdot}3$, N. 20° 20′. This is the Præsepe of the old astronomers in the constellation Cancer. A scattered cluster to the naked eye. 36 stars were counted in it by Galileo, but of course it contains many more. It has been photographed by Dr. Roberts, who thinks that the brighter stars are "nebulous."

M. 46: $7^{h}\ 37^{m}{\cdot}2$, S. 14° 35′. A little preceding the star 2 Puppis (Argo). Sir John Herschel called it "a superb cluster of stars, 12 . . . 16m." It includes a planetary nebula (Herschel), which Lassell, Lord Rosse, and Dr. Roberts found to be annular. Smyth describes it as "A noble though rather loose assemblage of stars from the 8th to the 13th magnitude."

M. 47: $7^{h}\ 50^{m}{\cdot}2$, S. 15° 9. This lies about 3° following the preceding, M. 46. Sir John Herschel says, "Place from Wollaston's Cat."

M. 49: $12^{h}\ 24^{m}{\cdot}7$, N. 8° 33′. It lies to the west of δ and ϵ Virginis, and nearly forms an equilateral triangle with those stars. Smyth calls it "A bright, round, and well-defined nebula." Webb says, "Faint haze in beautiful position between two 6th magnitude stars."

M. 50: $6^{h}\ 58^{m}\cdot 1$, S. 8° 12′. Between Sirius and Procyon, and about 4° south of the star 19 Monocerotis. Sir John Herschel described it as a remarkable cluster, very large and rich, with stars 12th to 16th magnitude. Smyth says it "is an irregularly round and very rich mass," and Webb calls it a "brilliant cluster." A photograph by Dr. Roberts in March, 1893, shows that it is not very rich. On his print the stars may be easily counted, and probably do not exceed 200 in the main body of the cluster.

M. 51: $13^{h}\ 25^{m}\cdot 7$, N. 47° 43′. This is the wonderful spiral nebula in Canes Venatici. It lies about 3° south preceding η Ursæ Majoris. Sir John Herschel described it as a double nebula, the larger with a nucleus and ring round it. Its spiral character was discovered by Lord Rosse, and his drawing agrees well in general outlines with photographs taken in April, 1889, and May, 1896, by Dr. Roberts, who finds "both nuclei of the nebula to be stellar, surrounded by dense nebulosity, and the convolutions of the spiral in this as in other spiral nebulæ are broken up into starlike condensations with nebulosity around them." The so-called second "nucleus" seems to be a portion which is being detached from the parent mass, probably by the "centrifugal force" of rotation. The nebula has also been well photographed by Dr. W. E. Wilson.

M. 52: 23^{h} 19^{m}·8, N. 61° 3′. About 1° south of the star 4 Cassiopeiæ. It is described by Sir John Herschel as large, rich, round, and much compressed, with stars 9th to 13th magnitude. Admiral Smyth saw it of a triangular form and "resembling a bird with outspread wings," and adds that "the field is one of singular beauty under moderate magnification." Lord Rosse thought it contained about 200 stars. A photograph by Dr. Roberts confirms the descriptions given by previous observers.

M. 53: 13^{h} 8^{m}·0, N. 18° 42′. A little north preceding the star α Comæ Berenices. It was described by Sir John Herschel as a bright globular cluster, very compressed in the centre, and stars of the 12th magnitude. Smyth calls it "a brilliant mass of minute stars from the 11th to the 15th magnitude, and from thence to gleams of star-dust with stragglers."

M. 54: 18^{h} 48^{m}·4, S. 30° 39′. About 2° preceding ζ Sagittarii. Sir John Herschel described it as "a globular cluster; bright; round; gradually brighter in the middle; 2½′ diameter; resolved into stars 15m., with a few outliers 14m."

M. 55: 19^{h} 32^{m}, S. 31° 13′. Sir John Herschel describes it as "globular; a fine large, round cluster; 6′ diameter; all clearly resolved into stars, 11, 12, 13m." Observing it with 3-inch refractor in the Punjab, the present writer saw glimpses of stars in it with power 40; it will not bear higher powers with this aperture.

M. 56: 19^{h} 12^{m}·7, N. 30° 0′. Between β Cygni and γ Lyræ, nearer the former. A globular cluster in a rich region. Sir John Herschel says resolved into stars of 11–14 magnitude. A photograph by Dr. Roberts shows it to be a globular cluster with rays of stars projecting from it.

M. 57: 18^{h} 49^{m}·9, N. 32° 54′. This is the well-known "annular nebula" between β and γ Lyræ. Drawings by Sir John Herschel and Lord Rosse agree well with photographs by Dr. Roberts; but it is more elliptical in shape than the drawings show. The central opening is not quite dark, but is filled in with faint nebulous light. A faint star in the centre is suspected of variable light. Lord Rosse, Secchi, and Chacornac thought this nebula might be resolvable into stars, but Huggins finds a gaseous spectrum. Recent photographs by Schaeberle show that it is really a spiral nebula.[1] (See next Chapter.)

M. 58: 12^{h} 32^{m}·6, N. 12° 22′. In the nebulous region in Virgo. Sir John Herschel says, "Bright; large; irregularly round; very much brighter in middle; resolvable."

M. 59: 12^{h} 37^{m}, N. 12° 13′. A little north of ρ Virginis. Smyth calls it "a bright little

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[1] *Astronomical Journal*, 539, 547.

nebula." It is in the same low-power field with M. 60.

M. 60: $12^h\ 38^m{\cdot}6$, N. 12° 6′. A little north of ρ Virginis, and in a low-power field with M. 59. Smyth describes it as "A double nebula . . . about 2′ or 3′ from centre to centre, the preceding one being extremely faint." There is another small nebula near.

M. 61: $12^h\ 16^m{\cdot}8$, N. 5° 2′. A little north of the star 16 Virginis. Smyth describes it as "A large pale-white nebula, but so feeble as to excite surprise that Messier detected it with his 3½-foot telescope in 1779." Webb says, "Faint; bright centre." Lord Rosse found it spiral. A photograph by Dr. Roberts in May, 1899, shows it to be "a right-hand spiral." [1]

M. 62: $16^h\ 54^m{\cdot}8$, S. 29° 56′. About 6° following and a little south of the star τ Scorpii. Messier described it as "resembling a little comet." Sir William Herschel resolved it into stars, and described it as a miniature of M. 3. Sir John Herschel says, "Globular cluster, bright; large; round; superb; about 7′ diameter; all resolved into stars 15 mag., very equal. The most condensed part is a perfect blaze, but not quite in the centre."

M. 63: $13^h\ 11^m{\cdot}3$, N. 42° 34′. A little north of the star 20 Canum Venaticorum. Sir John Herschel describes it as very bright and large, with a

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[1] *Knowledge*, August, 1901.

bright nucleus. A photograph by Dr. Roberts in May, 1896, with an exposure of 2 hours and 25 minutes, shows it to be a spiral nebula "with a bright stellar nucleus in the centre of dense nebulosity." Huggins finds a continuous spectrum.

M. 64: $12^h\ 51^m{\cdot}8$, N. 22° 13′. In Coma Berenices, about 1° north following the star Flamsteed 35. Sir John Herschel described it as very bright and large, and thought it resolvable. Lord Rosse found a dark spot on one side. Smyth says, "It is magnificent in size and brightness." Webb calls it a "Magnificent large bright nebula, blazing to a nucleus." A photograph by Dr. Roberts shows it to be a spiral nebula, "with a large bright stellar nucleus; one of the convolutions is very bright, with a dark space between it and the nucleus, which is free from nebulosity, thus producing the effect of contrast between dark and light spaces."

M. 65: $11^h\ 13^m{\cdot}6$, N. 13° 38′. A little south preceding the star 73 Leonis (south of θ Leonis). A photograph by Dr. Roberts shows it "to be a left-hand spiral, with the external outline so regularly formed that it resembles an annular nebula with rings encircling it; but the spiral form must be the true interpretation, and the rings of nebulosity, with the dark spaces between them, and the nebulous star-like condensations, together form parts of the convolutions; the dark spaces being the intervals between them."

M. 66. 11^{h} 15^{m}, N. 13° 32′. In the same low-power field with M. 65 (above). Lord Rosse found it to be spiral, and this is confirmed by a photograph taken in February, 1894, by Dr. Roberts, who says, "The photograph shows the nebula to be a spiral, with a well-defined stellar nucleus, which forms the pole of the convolutions in which I have counted fourteen nebulous star-like condensations." Smyth says that at a short distance following M. 65 and M. 66 there is another elliptical-shaped nebula of even larger apparent dimensions.

M. 67: 8^{h} $45^{m}\cdot 8$, N. 12° 11′. About 2° preceding α Cancri. Sir John Herschel described it as a remarkable object, very bright, large, and rich, with stars 10th to 15th magnitude. Smyth calls it a rich but loose cluster. A photograph by Dr. Roberts shows that the cluster is not very rich. It seems to contain about 200 stars, as estimated by Sir William Herschel.

M. 68: 12^{h} $34^{m}\cdot 2$, S. 26° 12′. In Hydra, about $3\frac{1}{2}°$ south of β Corvi, and near a $5\frac{1}{2}$ magnitude star. Sir John Herschel describes it as "A globular cluster, irregularly round; gradually brighter in the middle. . . . All clearly resolved into stars 12 m.; very loose and ragged at the borders."

M. 69: 18^{h} $24^{m}\cdot 5$, S. 32° 25′. About $2\frac{1}{2}°$ north following ϵ Sagittarii. Sir John Herschel described it as "A globular cluster; bright; round; 3′ diameter; all clearly resolved into stars, 14–15 mag. A blaze of stars."

M. 70: $18^{h}\,36^{m}{\cdot}3$, S. 32° 25′. About 2½° following M. 69 (above). Sir John Herschel describes it as "A globular cluster; bright; round; resolved into stars 15 mag."

M. 71: $19^{h}\,49^{m}{\cdot}3$, N. 18° 31′. Between γ and δ Sagittæ. Resolved into stars by Sir William Herschel. Sir John Herschel describes it as a very large and very rich cluster, with stars 11 to 16 magnitude. A photograph by Dr. Roberts shows a cluster in which the "curves and arrangements of stars resemble those of a spiral nebula." The surrounding region is "densely crowded with stars down to about 17th magnitude, arranged in remarkable curves and lines, which are very suggestive of having been produced by the effects of spiral movements."

M. 72: $20^{h}\,48^{m}$, S. 12° 54′. In Capricornus. A globular cluster discovered by Messier in 1780 as a nebula. Sir William Herschel resolved it into stars with his 20-feet reflector. He called it "a very bright object," and estimated its diameter at 1′ 53″·6.

M. 73: $20^{h}\,53^{m}{\cdot}5$, S. 13° 1′. In Capricornus, a little following M. 72. Sir John Herschel says, "Cluster ??; extremely poor; very little compressed; no nebula."

M. 74: $1^{h}\,31^{m}{\cdot}3$, N. 15° 6′. A little following η Piscium. Sir John Herschel thought this to be a globular cluster, very large and round, brighter in the middle, and partially resolved into stars;

but Lord Rosse found it to be a spiral nebula, and a photograph by Dr. Roberts, taken in December, 1893, confirms this, and shows it to be a perfect and beautiful spiral, "with a central stellar nucleus," and numerous "star-like condensations" in the convolutions of the spiral.

M. 75: 20^{h} 0^{m}·2, S. 22° 12′. Messier thought it to be a mass of very small stars. Sir William Herschel resolved it, and Smyth calls it a globular cluster. Webb says, "Bright nucleus, with low power."

M. 76: 1^{h} 36^{m}·0, N. 51° 4′. A little north of the star 54 Andromedæ. A double nebula, the companion being No. 193 of Herschel's 1st Class. Messier thought it was a cluster, but Sir William Herschel considered it irresolvable. Lord Rosse found it spiral, with two centres. Webb says, "Curious miniature of M. 27 [the dumb-bell], and like it, *gaseous*." A photograph by Dr. Roberts "shows the two nebulæ to be one only. . . . The figure of the nebula suggests that it is a broad ring seen edgewise."

M. 77: 2^{h} 37^{m}·6, S. 0° 26′. About 1° south following δ Ceti. Sir John Herschel describes it as pretty large and irregularly round, brighter in the middle, with a nucleus, and partly resolved. Lord Rosse and Lassell thought it spiral. A photograph by Dr. Roberts shows "a stellar nucleus, with projecting *ansæ* of dense nebulosity . . . and surrounding the *ansæ* is a zone of faint nebulosity surrounded by a broad nebulous ring, which is studded with strong condensations resembling stars with irregular margins." The surrounding region is very devoid of stars.

M. 78: $5^{h}\ 41^{m}{\cdot}6$, N. 0° 1′. About $2\frac{1}{2}^{\circ}$ north following ζ Orionis. Webb says, "Singular 'wispy' nebula." Lord Rosse thought it possibly a spiral.

M. 79: $5^{h}\ 20^{m}{\cdot}1$, S. 24° 37′. About $3\frac{1}{2}^{\circ}$ south of β Leporis. Seen by Sir William Herschel as a cluster about 3′ in diameter. Webb says, "Tolerably bright with my 64, blazing in centre; higher powers showed it mottled."

M. 80: $16^{h}\ 11^{m}{\cdot}1$, S. 22° 44′. About midway between α and β Scorpii, and a little north of 19 Scorpii. Sir William Herschel thought it the richest and most condensed mass of stars in the heavens. Sir John Herschel, in his "Cape Observations" (p. 111), describes it as "a globular cluster; round; suddenly very much brighter in the middle to a blaze . . . stars = 14 m.; all resolved. Fine object." In May, 1860, a temporary star of about the 7th magnitude blazed out in the centre of this nebula, and by its light completely obscured the cluster. On June 16 of the same year it had completely disappeared, and has not been seen since. A little north, following the nebula, are two known variable stars, R and S Scorpii.

M. 81: $9^{h}\ 47^{m}{\cdot}3$, N. 69° 32′. In Ursa Major, about 10° north-west of α. Described by Sir John Herschel as a remarkable, extremely bright nebula with a nucleus. Lord Rosse thought it very like the great nebula in Andromeda, and this is confirmed by a photograph taken by Dr. Roberts in March, 1889, with an exposure of 3½ hours; but it is very much smaller in apparent size. This photograph shows the nebula "to be a spiral, with a nucleus which is not well defined at its boundary, and is surrounded by rings of nebulous matter." Huggins finds a continuous spectrum, like that of the great nebula in Andromeda.

M. 82: 9^{h} 47^{m}·6, N. 70° 10′. About half a degree north of M. 81 (above). Sir John Herschel described it as a very bright ray, and very large. Lord Rosse called it a most extraordinary object. A photograph by Dr. Roberts shows that it "is probably seen edgewise with several nuclei of nebulous character involved." Huggins find the spectrum to be continuous. This is a characteristic of the spiral nebula.

M. 83: 13^{h} 31^{m}·4, S. 29° 22′. Sir John Herschel says, "Very bright; very large; suddenly much brighter in middle to a nucleus; large 3-branched spiral."

M. 84: 12^{h} 20^{m}·0, N. 13° 26′. Closely preceding M. 86. Sir John Herschel says, "Very bright; pretty large; round; pretty suddenly much brighter in middle; resolvable."

M. 85: 12^{h} 20^{m}·4, N. 18° 45′. A little east of 11 Comæ Berenices.

M. 86: 12^{h} 21^{m}, N. 13° 30′. In "the nebulous region" in Virgo. Sir John Herschel thought it probably resolvable.

M. 87: 12^h 25^m·8, N. 12° 56′. In the nebulous region in Virgo. A little preceding M. 89. Sir John Herschel says, "Very bright; very large; round; much brighter in the middle."

M. 88: 12^h 26^m·9, N. 14° 58′. A long and faint nebula in the nebulous region in Virgo. Smyth called it "A long, elliptical nebula." Lord Rosse thought it possibly spiral.

M. 89: 12^h 30^m·6, N. 13° 6′. In the nebulous region in Virgo. A little following M. 87 (above). Sir John Herschel says, "Pretty bright; round; gradually much brighter in the middle."

M. 90: 12^h 31^m·9, N. 13° 42′. In the nebulous region in Virgo. A little north of M. 89 (above). Sir John Herschel says, "Pretty large; nucleus."

M. 91. In the nebulous region in Virgo. Sir John Herschel doubted the existence of this nebula.

M. 92: 17^h 14^m·1, N. 43° 15′. In a rather blank space in Hercules, about 6° north of π. Messier found it easily visible with a telescope of only one foot in length. Sir William Herschel found it a brilliant cluster of 7′ or 8′ in diameter. Sir John Herschel described it as "a globular cluster, very bright and large, and well resolved into small stars." Webb says, "A very fine cluster, though not equal to M. 13; less resolvable; intensely bright in centre." A photograph by Dr. Roberts in May, 1891, shows the cluster "involved in dense nebulosity." But Professor Barnard finds that there is no trace of any real nebulosity in any of the great globular clusters as seen with the great Yerkes telescope. The nebulosity visible on the photographs is therefore probably due to a photographic effect.

M. 93: 7^h 40^m·2, S. 23° 28′. A little following ξ Puppis (Argo). Sir William Herschel resolved it into stars 8 to 13 magnitude. Smyth calls it "A small galaxy cluster," and says, "This neat group is of a star-fish shape, the south preceding portion being the brightest. Webb says, "Bright cluster in a rich neighbourhood."

M. 94: 12^h 46^m·2, N. 41° 40′. A little to the north of a line joining α and β Canum Venaticorum. Sir John Herschel describes it as large, very bright, and irregularly round, with bright nucleus and barely resolvable. Lord Rosse saw a dark and bright ring round the nucleus, and thought it probably spiral. A photograph by Dr. Roberts in May, 1892, shows the stellar nucleus and rings, but, he says, "I am unable to trace any spiral structure on the photograph."

M. 95: 10^h 38^m·7, N. 12° 13′. About 4° north following ρ Leonis. Discovered by Méchain in 1781. Sir John Herschel says, "Bright; large; round; pretty gradually much brighter in middle to a nucleus." Lord Rosse saw two ellipses, and the centre perhaps resolvable.

M. 96: 10^{h} 41^{m}·5, N. 12° 21′. About 40′ east of M. 95 (above). Discovered by Méchain in 1781. Sir John Herschel says, "Very bright; very large; a little elongated; very suddenly very much brighter in the middle, barely resolvable." Smyth says, speaking of this and M. 95, "Another round but not equally defined nebula, large and of a pale white colour." A little north of M. 96 are two faint nebulæ, Nos. 17 and 18 of Sir William Herschel's Class I.

M. 97: 11^{h} 9^{m}·0, N, 55° 34′. About 2° south following β Ursæ Majoris. Described by Sir John Herschel as a remarkable planetary nebula, very bright, very large, and about 160 seconds of arc in diameter. Lord Rosse resembled it to the face of an owl, and it has hence been known as "the owl nebula." A photograph by Dr. Roberts in April, 1895, shows it of an elliptical shape, about 203 seconds in diameter, with a 15th magnitude star in the centre, but no other stars in the nebula. He says, "The star seen by both Lord Rosse and Dr. Robinson has disappeared."

M. 98: 12^{h} 8^{m}·7, N. 15° 27′. Closely preceding the star 6 Comæ Berenices. Smyth says, "A fine and large but rather pale nebula . . . elongated in the direction of two stars."

M. 99: 12^{h} 13^{m}·7, N. 14° 58′. A little south following the star 6 Comæ Berenices. Sir John Herschel describes it as a very remarkable object, bright, large, and round. Lord Rosse found it to be a wonderful spiral. A photograph by Dr. Roberts confirms the spiral character, and shows "many star-like condensations in the convolutions."

M. 100: 12^{h} $17^{\text{m}}\cdot 9$, N. 16° 23′. About 2° north following 6 Comæ Berenices. Discovered by Méchain in 1781. Smyth thought it "globular," but Lord Rosse found it to be a spiral, with the centre a planetary nebula. A photograph by Dr. Roberts in May, 1896, shows it to be "a strikingly perfect" spiral, with a sharply stellar nucleus "in the midst of faint nebulosity."

M. 101: 13^{h} $59^{\text{m}}\cdot 6$, N. 54° 30′. About 6° east of ζ Ursæ Majoris. Sir John Herschel describes it as pretty bright, very large, and irregularly round. Lord Rosse found it to be a large spiral nebula, 14′ in diameter; and his drawing agrees fairly well with a photograph taken by Dr. Roberts in May, 1892, which shows "a well-defined stellar nucleus," with the usual convolutions and "star-like condensations."

M. 103: 1^{h} $26^{\text{m}}\cdot 6$, N. 60° 11′. About 1° north-east of δ Cassiopeiæ. Sir John Herschel describes it as a bright cluster, pretty large, round and rich, with stars 10th and 11th magnitudes. A photograph by Dr. Roberts shows stars down to about the 15th magnitude. It contains bright and faint stars, but the cluster does not seem to be a very rich one. Smyth called it a "fan-shaped group," and the photograph confirms this description.

XXI

The Ring Nebula in Lyra

THIS annular nebula lies between the stars β and γ Lyræ, and about 6¾° south and a little to the east of Vega. It is a favourite object with amateur telescopists, being probably the only object of its class within the range of moderate-sized instruments. It was discovered by Darquier in 1779, and it is No. 57 in Messier's Catalogue of Nebulæ; but neither of these observers seems to have noticed its real form. To Sir William Herschel it appeared as a luminous ring of nebulous light with a dark centre. Schroter, in 1797, and Sir John Herschel, in the nineteenth century, saw a fainter light filling up the interior of the ring; and photographs with long exposures show so much nebulous light within the ring as almost completely to obliterate its annular aspect. Secchi and Chacornac thought it resolvable into small stars, but Sir William Huggins found a gaseous spectrum.

The ring is not perfectly circular, but oval in shape. According to measures made by Professor

Barnard in 1893–94[1] its apparent dimensions are as follows:—

Outer Major diameter	80″·89
Inner „ „	36″·52
Outer Minor diameter	58″·81
Inner „ „	29″·36

In apparent size, therefore, it is considerably larger than Saturns' rings.

From the above measures it appears that the width of the ring varies from about 14″ to 22″. The ring is not uniform in brightness, but somewhat fainter at the ends of the longer axis, and a little brighter at the ends of the shorter axis. This feature, which was noticed by Sir William Herschel in 1785, is, however, only noticeable on photographs taken with short exposures. Barnard finds it a "beautiful object" with the great Yerkes telescopes of 40 inches aperture, and discovered another nebula of a spiral form distant about 4′ from the centre of the ring. With reference to the larger nebula he says, "Under the best conditions the interior of the ring has appeared of unequal brightness. The light of the ring itself, however, blinds one's eye to the details on the interior, so that it is not possible to speak with certainty of the form of the details."

The real shape of this wonderful object is probably that of an ellipsoid of revolution. This ellipsoid being hollow, or partly so, and nearly

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[1] *Monthly Notices*, R.A.S., January, 1900.

transparent, gives it the appearance of a ring. Professor Schaeberle has recently found indications on photographs that the nebula forms the centre of a larger spiral structure.[1] The spectrum of the nebula shows a number of bright lines. These indicate the presence of hydrogen and another substance, but helium seems to be absent.

There are many faint stars in the same field with the nebula, and one very faint one in the centre, which has been suspected of variable light. It seems to have been first seen by Von Hahm in the eighteenth century, for he speaks of its disappearance in 1800. It was apparently not seen by Sir William Herschel, nor by Sir John Herschel, but it was observed by Lord Rosse in 1848, and by Secchi in 1855. It was, however, missed by Professor Asaph Hall in 1877 with the 26-inch refractor of the Washington Observatory, and by Vogel with 27 inches in 1883. But it is visible on all photographs, which shows that its light, like that of the nebula, is strongly actinic. An exposure of a few minutes' duration is sufficient to show it. In 1899, MM. Bourget, Montangerand, and Bailland published observations tending to show that this small star had increased in brightness in recent years; but Barnard, from over 10 years' observations with the Lick and Yerkes telescopes, thinks that there has been no change in its light. In July, 1899, he estimated it as 15½ or 16th

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[1] *Astronomical Journal,* No. 539.

magnitude,[1] and Burnham, in 1891, rated it 15·4 m. The photographic and spectroscopic evidence shows that this small star is most probably connected with the nebula, and Barnard, Keeler, and Scheiner agree that it forms the nucleus of the nebula. Keeler says, "It is as clearly defined as are other stars outside the nebula;" but according to Dr. Roberts, other nebulæ have a stellar nucleus. There is another extremely faint star just inside the ring. This small star is distinctly visible on a photograph taken by Keeler with an exposure of 10 minutes. He says, "It is at the very limit of vision with the 36-inch, and must, like the central star, possess unusual photographic energy."[2]

Recent measures made by Dr. Burt L. Newkirk to determine the parallax of the central star gave a result of about $\frac{1}{10}$ of a second of arc. He used sixteen comparison stars on different sides of the nebula, and he thinks this parallax is worthy of confidence, and that we are justified in regarding the nebula "as one of our nearest celestial neighbours."[3] Assuming this parallax, we have, from Barnard's measures, the outer length of the ring about 809 times the sun's distance from the earth, and its outer width 588 times the same distance. The inner length and width would be about 365 and 294 times the sun's distance, and as Dr. Newkirk

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[1] *Monthly Notices*, R.A.S., January, 1900, p. 253.

[2] *Astrophysical Journal*, June–December, 1899, p. 195.

[3] *Publications of the Astronomical Society of the Pacific*, February 10, 1904.

says, "The whole solar system could be put into the ring with plenty of room to spare." He might have said *several* solar systems, as the diameter of Neptune's orbit is only a little over 60 times the sun's distance from the earth. The parallax found by Newkirk indicates a "light journey" of about 33 years, and it also follows that light would take about 4 days 16 hours to pass from one extremity of the ring to the opposite end. Placed at the distance of the nebula, our sun would shine as a star of about the 5th magnitude, or over 15,000 times brighter than the central star. This small star must therefore be a comparatively faint object. Seen from the extremity of the ring, it would, I find, shine as a star of about -3 magnitude, or between Venus and Jupiter in brightness.

The ring nebula lies about $6\frac{3}{4}°$ from the bright star Vega, for which Dr. Elkin finds a parallax of $0''{\cdot}082$, or only a little less than that found by Dr. Newkirk for the nebula. From the relative distances indicated by these parallaxes, I find that the distance of the nebula from Vega is about one-fourth of its distance from the earth. Hence, it would follow that the ring nebula, as seen from Vega, or rather from a planet revolving round Vega, if such there be, would shine 16 times brighter than we see it. This represents 3 stellar magnitudes, so that it might perhaps be visible to the naked eye, or at least with a very small telescope.

XXII

A Great Belgian Astronomer

ALTHOUGH perhaps unknown to the general public, one of the greatest Belgian astronomers of the nineteenth century was Jean Charles Houzeau. He accomplished much excellent work in astronomy, which has rendered his name for ever immortal in the history of the "sublime science." Houzeau was born in the suburb of Havre near Mons, on October 7, 1820, on a small property owned by his parents. He was the elder of two sons, and his brother, Auguste Houzeau, became professor at the School of Mines at Mons, and a member of the Chamber of Representatives.

Like many other great men, Houzeau was a precocious child. Before he could read or write he showed an evident taste for astronomy, and it is said of him that with the sweetmeats given him by his parents and friends he used to make figures representing the constellations on a table! In his studies at the college of Mons he achieved a brilliant success, and was awarded a silver medal for his zeal and hard work. He entered the

University of Brussels in 1837, but here he was not so successful, either from indifference to honours and distinctions or on account of his taste for original investigation. Disappointed by his want of success at the University, his parents brought him home to Mons, and here he was free to follow his astronomical studies. He built with his own hands a small observatory on a hill called Panisel, situated near his father's residence. It merely consisted of a wooden hut, and contained a mural circle, a transit instrument, and a telescope mounted equatorially. The tubes of these instruments were of zinc, and the lenses, which were purchased in Paris, were not even achromatic! This equipment, although a very imperfect one for the study of astronomy, shows the taste and aptitude of the young astronomer, who was then only eighteen. Shortly after this, in the years 1838 to 1841, Houzeau became a journalist, and wrote a considerable number of articles in a Brussels paper called *Emancipation.* The papers were on various subjects, such as the conservation of forests, the use of air as a motor, the application of geology to agriculture, civil architecture, steam-engines, navigable canals, the improvement of railways, artesian wells, etc., a remarkable series of articles for so young a man. He also wrote a small work on turbines, their construction and application to industrial purposes, but this work is now unfortunately lost.

During the years 1840 and 1841, young Houzeau studied a course of science at Paris. He returned to Belgium in 1842 and resumed his astronomical studies, in which he was encouraged by Quetelet, then Director of the Brussels Observatory, who permitted him to act as a voluntary assistant in certain observatory work.

About this time Houzeau sent a paper to the *Astronomische Nachrichten* on the Zodiacal Light, and this note was referred to by Humboldt in his famous "Cosmos." Up to this Houzeau was quite unknown in the astronomical world. During the years 1843 and 1844, he paid many visits to Paris, and studied astronomical works in the National Library. In 1844 he published an important paper in the *Astronomische Nachrichten* on the binary stars, 61 Cygni, and 70 Ophiuchi. With reference to the latter star he showed that there was an irregularity in its apparent motion which seemed to indicate that either the component stars did not follow Newton's laws of gravitation, or else that the centre of motion is not the centre of gravity of the masses. This irregularity in the motion of 70 Ophiuchi is now well known, but has not yet been very satisfactorily explained. Houzeau ascribed it to an effect caused by the aberration of light, but this view was contested by Sir John Herschel in the *Astronomische Nachrichten* (No. 520).

From the year 1844, Houzeau made meteorological as well as astronomical observations at the Brussels Observatory. On August 3 of that year he presented to the Belgian Academy of Sciences an important paper on the August meteors, and showed how to determine the "radiant" point. In the year 1845 he sent some papers on comets to the Belgian Academy, but for some reason these were not published. About this period he seems to have first thought of compiling an astronomical bibliography. His idea was to continue the work of Lalande, which stopped in 1802. This great work, on which he spent an enormous amount of labour, was completed and published in Brussels in 1887, the year before his death.

On September 30, 1846, Houzeau was appointed assistant astronomer at the Brussels Observatory, on the small salary of 1400 francs, or about £56 a year. He occupied this position for about three years, and during that period he communicated no papers to the Academy, his whole time being devoted to the duties of his office. His labours and zeal were much thought of by Quetelet, who speaks highly of Houzeau in the *Annals de l'Observatoire de Bruxelles* (1851). During his stay at the Observatory, Houzeau observed the transits of Mercury across the sun's disc, which took place on May 8, 1845, and November 8, 1848. He also observed a comet, discovered by Colla at Parma, and computed its orbit. In October and November, 1846, he undertook a series of observations of the planet Neptune which had then been recently discovered. In 1848 and 1849 he published a number of articles of a democratic and republican character, and on account of his political views he was dismissed from his post on April 6, 1849, notwithstanding Quetelet's efforts on his behalf.

In September, 1849, Houzeau left Belgium, accompanied by two friends, for an excursion in Germany, Switzerland, and France. They travelled partly on foot and partly by railroad and diligence, and visited several places of interest. In May, 1850, he went to Paris and remained there till 1855. During this period he had no regular occupation, but studied in the National Library and accumulated an enormous number of notes on all sorts of subjects. He then went to England, and, assisted by his brother, made some experiments on the possibility of optical telegraphy by means of lights, but his labours ended in no practical result.

In the years 1851 to 1854, Houzeau wrote several papers on physical geography and geodesy. In November, 1854, he was appointed astronomer to the Belgian War Department to assist in the topographical survey of the country. This work was carried on in summer in the field, and Houzeau passed the winter in Paris, reducing his observations, and, in his leisure hours, studying in the

School of Mines. His work on the survey of Belgium was continued until May, 1857, when, from want of funds, the work was stopped. Notwithstanding his arduous work in these years he still found time to write newspaper articles on various subjects, some astronomical. In 1857 he published an important work on physical geography, entitled "Histoire du Sol de l'Europe." In maps illustrating this volume he shows the varying heights of the ground by "contour lines," or lines of equal height and by tints, and this method of map-making, now frequently employed, seems to have been invented by Houzeau.

After losing his post in the War Department, Houzeau returned to Mons, and prepared for a visit to America, a journey which he had long contemplated. On June 21, 1857, he started for Brussels, and on July 1 he proceeded to London, and resided there for two months in order to improve his knowledge of English. On September 10 he sailed from Liverpool on board the sailing-ship *Metropolis* for New Orleans. The voyage lasted seven weeks, and after some rough weather, and rather scanty fare, the ship arrived at New Orleans on October 28. Although his intention was, on leaving England, to spend only a few months in the United States, his visit to America extended over a period of nearly twenty years! During this period of his life a large portion of his astronomical work was done. He also wrote a number of papers on the manners, customs, and institutions of the United States. These accounts were communicated to a periodical called *Revue Trimestrielle*, during the years 1858 to 1868, and included a discussion on the abolition of slavery, a subject in which he always took the deepest interest.

After spending a short time in New Orleans, he proceeded, in company with a caravan of farmers, to Texas, a country almost absolutely unknown at that time. After numerous adventures on the prairies, Houzeau arrived on May 21, 1858, at the small town of San Antonio. While here, he was employed by a company to do some survey work for irrigation purposes. He then joined another caravan, and proceeded on an excursion to the Rio Grande, the large river which forms the boundary between Texas and Mexico. The journey there and back lasted from September 1 to October 15, 1858, and during that time he made some interesting meteorological observations. It was then that the famous comet of Donati shone so brilliantly in the evening sky. It was first seen by Houzeau on September 19, and he remarked that it passed over the stars σ and ρ Bootis without obscuring their light. Soon after his return to San Antonio, Houzeau was again employed by the company mentioned above to make some explorations to the west of Texas. This work occupied him for four years, during which he passed a wandering life, living chiefly in the open air, investigating the climate and the mineral and other resources of a country as large as France.

At the beginning of the year 1861, the war between the Northern and Southern States broke out. At this time Houzeau was about to undertake a geological excursion to the most distant part of the prairie, and on the completion of this work he returned to San Antonio. After a short rest he proceeded on a second geological expedition to the Rio Pecos, but owing to the political state of the country he was obliged to return. After a little, Houzeau left San Antonio and went to a town called Austin. Here some of his friends tried to induce him to join the staff of the Confederate Army in the capacity of an engineer, but he firmly refused to have anything to do with upholding the cause of slavery. After a short residence at Austin, he returned to San Antonio, and occupied his time with his intellectual labours. But owing to his sympathy with the negroes, he was not long permitted to remain in peace; and as the authorities tried to compel him to join the militia, in spite of his protestations made through the Belgian Consul at New Orleans, he determined to leave San Antonio and proceed to Mexico. After several adventures on the journey, he arrived safely at Matamoros, near the mouth of the Rio Grande, on March 20, 1862. Here he remained for some months, and supported himself by gardening and architectural work on buildings in the town. Wishing to visit the United States, he succeeded, after some difficulty, in obtaining a free passage on an American warship bound for New Orleans, and arrived in that city on January 31, 1863. Here he lived for five years—with the exception of a visit of four months to the city of Philadelphia. During his sojourn in New Orleans he wrote many articles, under the name of Dalloz, for a journal called the *Union*, published in the interests of the negroes, for whom Houzeau always had the greatest sympathy. He soon became editor of this paper; and during his absence in Philadelphia its name was changed to the *Tribune*. On his return to New Orleans he was appointed director of the journal, and for over three years he continued to champion with energy the cause of the negroes. The number of articles he wrote for the *Tribune* was prodigious and sufficient to fill several large volumes. His labours in the negro cause aroused the animosity of the planters, and he experienced much persecution on account of his views. Some disagreement between Houzeau and the administrators of the *Tribune* led to his resignation, which was accepted on January 18, 1868, and on April 25 of the same year the journal ceased to exist.

During his residence in America, Houzeau wrote several astronomical papers for European journals. Among these was one "on the determination of the radius vector of a new planet," in which he showed a new method for finding the distance of a planet from the sun, and calculating the elements of its orbit. He also wrote papers on the parallax of the planets, and on the proper motions of the stars.

His connection with journalism in New Orleans having come to an end, Houzeau resolved to proceed to Jamaica, an idea which he had long entertained. On May 17, 1868, he left New Orleans, and on June 5 arrived at Kingston, one of the principal ports of the island. Houzeau lived in Jamaica for about six years, and would probably have remained there for the rest of his life had not the death of Quetelet, in 1874, recalled him to Brussels to undertake—at the urgent request of his friends—the Directorship of the Brussels Observatory. Some of the most important work of Houzeau's active life was accomplished during his residence in Jamaica. Soon after his arrival at Kingston, he rented a farm a few miles from that town. Here he remained only a year, and in 1869 he removed to a place a few miles farther away, called Rose View, at the foot of the Blue Mountains. His new residence was a small house, to which was attached a garden of about 2½ acres, containing cocoanut palms, mango trees, guavas, pine-apples, etc. Here, again, Houzeau found himself in the midst of a negro community, who at first showed symptoms of hostility, but finding that Houzeau was in sympathy with them, they soon became his friends. In this beautiful climate his life seems to have been a happy one, free from the cares and excitement of more civilized regions. For servants he had a young mulatto, named William Lang, who came with him from New Orleans, and a young negro, named Georges Hall, and both seem to have been devoted to his service.

While in Jamaica, Houzeau made several excursions into the interior of the island, and one expedition—undertaken in 1873—to the summit of the Blue Mountains seems to have been almost a "voyage of discovery," as in those days these mountains were comparatively unknown to travellers.

By the aid of a small printing press, and with the help of his two attendants, Houzeau printed several small works during his stay in Jamaica. These were chiefly on mathematical subjects; and as only a few copies were printed they are now extremely rare. He also wrote many other papers on subjects connected with astronomy and natural history. For the study of the latter subject he seems to have always had a great aptitude; and, indeed, his work, "Études sur les facultés mentales des animaux comparées à celles de l'hommes," would alone have been sufficient to establish his fame as a great philosopher and naturalist. Some have even placed his writings on this subject in the same rank as those of the illustrious Darwin.

Among his astronomical labours at Jamaica may be mentioned his observations on the Zodiacal Light, and his "Atlas of stars visible to the naked eye." The latter work is one of considerable importance, executed as it was in a beautiful climate like that of Jamaica, and at a station situated not far from the Equator, a position which enabled this eminent observer to see nearly all the stars in *both* hemispheres. About thirty years before Houzeau commenced his survey of the heavens, the famous Argelander had published maps of the northern hemisphere and a portion of the southern. This work was afterwards revised by Heis; and Behrmann had published a similar work for the southern hemisphere. Houzeau's work has, however, the advantage of having been accomplished by *one* observer for both hemispheres. This work was commenced on February 25, 1875. At first Houzeau feared that it would be an undertaking of great magnitude and labour, but after a few days' experience he came to the conclusion that it would be a comparatively easy task. Before three months had elapsed he found that one-third of the work was done. It has been estimated from Argelander's observations in the northern hemisphere that the total number of stars visible to the naked eye in *both* hemispheres would be about 4200. Houzeau's maps shows nearly 6000, an increase partly explained by the clearer skies of Jamaica, and partly, Houzeau thought, by the difficulty of seeing southern stars near the horizon of Argelander's station. To enable him to see the stars further south, Houzeau went to Panama on October 16, 1875, and having there completed his maps, he returned to Jamaica on December 16 of the same year. Here he found a telegram awaiting him, announcing his appointment as Director of the Brussels Observatory.

Before relating Houzeau's subsequent career, let us further consider his star atlas. In addition to all the stars visible to the naked eye, he added a drawing of the Milky Way, shown blue on a white ground. His drawing is somewhat diagrammatic and deficient in detail. The method of delineation adopted by Houzeau was to trace the lines of equal brightness (or "isophotes," as he termed them) of the various portions of the Milky Way. These somewhat resemble, he says, the "contour lines" on terrestrial maps, and are filled in with a blue tint, the washes of colour being placed one over the other, so that "plus il y a de courbes, plus l'espace renfermé dans la dernière est brillant." As in Heis' drawing of the Milky Way, Houzeau shows five gradations of brightness, and these he determined by comparing the brilliancy of different portions with neighbouring stars of magnitudes, 6–7, 6, 5–6, 5 and 4–5. In making this comparison he was guided by the appearance or disappearance of the luminous patches of Milky Way light in the twilight or moonlight simultaneously with the stars of comparison. It seems doubtful, however, whether this method is susceptible of any great accuracy, the comparison of a bright point like a star with a nebulosity extending over a considerable area being evidently a matter of much difficulty and considerable uncertainty. The visibility of the star and the adjoining nebulosity might not, in all cases, be equally affected by varying atmospheric conditions, and the gradations of light in the different portions of the galaxy are so gradual, numerous and complicated, that many of the smaller details would unavoidably be lost. Houzeau seems to have been conscious of the uncertainty of his method, for he says: "Cependant il ne serait pas exact d'en conclure que ces plaques brillants donnent autant de lumière qu'une nappe continue d'étoiles du 5m ordre, il est incontestable que leur étendue aide à les apercevoir, et que leur visibileté ne repose pas uniquement sur leur éclat spécifique." The drawing being, however, the work of a single observer, and so accomplished an astronomer as Houzeau, and moreover executed from observations made in a favourably situated station, like Jamaica, possesses a value to which it might not otherwise be entitled.

As has been said, Houzeau was, in December, 1875, offered the appointment of Director of the Brussels Observatory. But some of the Belgian Ministers had opposed his nomination, owing to his well-known republican opinions. They even induced the king to cancel his nomination. However, these difficulties were surmounted by his friends, and in the beginning of 1876 his appointment to the Observatory was definitely decided. Houzeau left Jamaica on March 25, 1876, and on June 17 of the same year he took over charge of the Observatory. He at once commenced a thorough reorganization of the establishment, which had for some years become much out of date both as to its instruments and its management. During the six years he remained in charge of the Observatory he made many changes. On his arrival there were only four assistants, but when he retired in 1883 the number was sixteen. In the way of instruments he added equatorial telescopes of 6 and 15 inches aperture, constructed by Cooke of York, a meridian circle of 6 inches, the work of Repsold, and other instruments. During his superintendence of the Observatory he laboured as usual with great zeal, and the amount of work accomplished was very considerable. Many works were published during this period, including the star atlas already referred to.

In 1882, Houzeau, accompanied by two assistants, went to his former place of residence, San Antonio in Texas, to observe the transit of Venus, which took place in December of that year. His observations were only partially successful, owing to the presence of clouds during the early phases of the phenomenon. On his return to Europe he remained for some time at Orthez, near Pau, and afterwards at Blois. In November, 1883, he resigned the Directorship of the Brussels Observatory, and in 1886 he returned to Brussels and resided there till his death.

After his retirement from the Observatory, his time was chiefly devoted to the completion of his "Bibliographic Astronomique," a work already referred to in the beginning of this sketch. His health, never very robust, became much impaired, and after considerable suffering, he expired on July 12, 1888. His remains were conveyed to his native place, Mons, and there interred on July 15. He was twice married, but left no children.

Houzeau possessed many noble traits of character. He was charitable, honourable, just, modest, and frank. Outwardly he was somewhat reserved in manner, but he had a warm heart and was a good and constant friend. He was held in high esteem by the members of the Observatory. His object in life seems to have been to help in the cause of humanity and science. His studies included almost all branches of human knowledge. He was a veritable encyclopædia. During his active life he gave his attention to astronomy, meteorology, geography, geodesy, philosophy, literature, political economy, etc. Although he made no great discovery in astronomy, his published works show great knowledge and judgment, and an original treatment of his subject, which renders them very interesting and instructive, not only to scientific students, but also to the general reader. The famous French astronomer, Flammarion said of him, "Houzeau was a laborious student, an independent man, a noble heart, and a grand character. He always placed the love of science and truth above personal interest, and the vain ambitions to which many students sacrifice their lives. His name will remain nobly associated with the history of contemporary astronomy, of which he was one of the most genuine representatives. His beautiful career, alas! too short, was wholly devoted to the cause of Progress."

XXIII

Some Recent Advances in Stellar Astronomy

ASTRONOMICAL discoveries are now being rapidly made. This is partly due to the large telescopes which have been recently constructed, and partly to the increased interest now taken by amateurs and the general reader in "the sublime science." Almost daily we hear of something new, and books on astronomy become rapidly out of date. In the following pages I propose to consider the most important advances which have been made in the department of stellar astronomy during the seven years 1894 to 1900,[1] the closing years of the nineteenth century.

Let us first consider the results of investigations made on the distance of the stars from the earth. For the five stars in the Plough, β, γ, δ, ϵ, and ζ, which are known to have a common proper motion—that is, that they are apparently travelling through space in the same direction and at nearly the same rate—Dr. Höffler finds a parallax

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[1] For an account of advances prior to 1894, see my work "The World of Space."

of 0″·0165. This makes their distance from the earth about 200 years' journey for light. On Mr. Monck's scale, of which the unit is the distance of a star with a parallax of one second of arc, their distance would be represented by 60·6. Placed at this vast distance, the sun would, I find, be reduced in brightness to a star of about 8½ magnitude, and would therefore be quite invisible to the naked eye! From this it will be seen that they must be very large and brilliant suns. If the observed parallax is correct, the actual distance from β to ζ would be at least four million times the sun's distance from the earth. Such is the scale on which the heavens are constructed. The spectra of all five stars are of the first or Sirian type, a fact which probably indicates an intrinsically brighter body than our sun. Dr. Höffler thinks that ϵ is 40 times brighter than Sirius.

From a series of measures made in different years, Sir David Gill finds that the parallax of Sirius is 0″·370, and he thinks that the parallax of this brilliant star has now been satisfactorily determined. He finds that the parallax of α Centauri—the nearest of all the stars to the earth—certainly lies between 0″·74 and 0″·75. This implies a distance of about 275,000 times the sun's mean distance from the earth, or about 25 billions of miles. Dr. Gill thinks that the parallax of the bright star Rigel is not more than 0″·01, which implies that the star's distance is certainly greater than 20 million times the sun's distance, and a light journey of 325 years. And yet it is one of the brightest stars in the sky—about seventh on the list. For Canopus, Gill finds no measurable parallax, a result which is very remarkable, as, next to Sirius, it is the brightest star in the heavens.

Parallaxes have been found at the Yale Observatory (U.S.A.) for the ten brightest stars in the northern hemisphere, viz. Arcturus, Capella, Vega, Procyon, Betelgeuse, Altair, Aldebaran, Pollux, Regulus, and α Cygni, with the result that Procyon is the nearest and α Cygni the furthest from the earth. Arcturus, the brightest of the ten, has a very small parallax, and must therefore be a sun of enormous size.

With reference to stellar motions, it had been for many years considered that the star Groombridge 1830—the so-called "runaway star"—had the largest proper motion—about 7 seconds of arc per annum; but now Mr. R. T. A. Innes and Professor Kapteyn have discovered that a star of the 8th magnitude, in the southern constellation Pictor, has a proper motion of 8·7 seconds per annum. The faintness of this new "runaway" is remarkable. Sir David Gill finds a parallax of 0″·312. At the distance indicated by this comparatively large parallax, the sun would shine as a star of about 2·6 magnitude. This makes the sun about 144 times brighter than the star.

As is now well known, the actual velocity of a star in the line of sight can be measured with the spectroscope. Some large velocities have recently been found in this way by Professor Campbell, now director of the Lick Observatory. For μ Cassiopeiæ he finds 60 miles a second; for ϵ Andromedæ, 52; for μ Sagittarii, 47; η Cephei, 46; ζ Herculis, 33½; and for the planetary nebula G.C. 4373, 31½ miles—all approaching the earth. For those receding, θ Canis Majoris and δ Leporis show a velocity of 59 miles a second. That a gaseous mass like a planetary nebula should be rushing through space with a velocity of over 31 miles a second, seems very extraordinary.

A variable velocity in the line of sight has been observed in a number of stars, which suggests that they are binary stars, with the components so close together that no telescope could divide them. Among these may be mentioned Capella, Castor, ζ Ursæ Majoris, β Aurigæ, β Herculis, η Pegasi, o Leonis, χ Draconis, ζ Geminorum, ι and κ Pegasi, θ Draconis, λ Andromedæ, ϵ Ursæ Majoris, ω Draconis, β Capricorni, ζ Centauri, μ Scorpii, π Cephei, and the Pole Star. Of these Capella is a most interesting object. According to the spectroscopic observations, the relative velocity of the components is about 37 miles a second, and the period of revolution about 104 days. Attempts to see the star visually double, made with the great telescope of the Lick Observatory, have failed;

but several of the Greenwich observers have seen the star "elongated" with the 28-inch refractor. The observed changes in the relative positions of the components agree well with the period of 104 days found with the spectroscope, and from the measures made it has been computed that the combined mass of the components is about 18 times the mass of our sun. The measures also show that the parallax found by Dr. Elkin (0″·081) is about correct. Professor Campbell finds that one component of Capella has a spectrum of the solar type, while the other is of the type of Procyon. The components do not differ much in brightness. (See chapter on Spectroscopic Binaries.)

The Pole Star has also been found to be a binary star, with a period of about 4 days.[1] The orbit is nearly circular, and in dimensions about the same as that of the moon round the earth. The presence of a third body is suspected.

The brighter component of the well-known double star Castor was found by Dr. Belopolsky to be a close spectroscopic binary. The period is about 3 days, and the relative orbital velocity about 20·7 English miles a second.

From spectroscopic measures of motion in the line of sight of the famous binary star γ Virginis Belopolsky finds a parallax of 0″·051, and a combined mass equal to 15 times the mass of the sun.

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[1] More exactly, 3 days, 23 hours, 14·3 minutes.

The system is receding from the earth at the rate of nearly 13 miles a second. He makes a similar calculation with reference to the binary star γ Leonis, finding a parallax of $0''\cdot0197$, and a mass of $6\frac{1}{2}$ times the sun's mass; but he seems to be unaware of the fact that the orbit of γ Leonis is very uncertain.

Belopolsky finds that the velocity of 61 Cygni (the nearest star to the earth in the *northern* hemisphere), as derived from spectrum photographs, is about 26·8 miles a second towards the earth. Assuming a parallax of $0''\cdot5$, and a proper motion of 5·2 seconds, the velocity *across* the line of sight would be about 22·6 miles a second. Combining these velocities, he finds an *actual* velocity through space of 35 miles a second.

With reference to double and binary stars, some interesting results have been found. Professor Barnard, observing with the great 40-inch telescope of the Yerkes Observatory (U.S.A), in 1897, found a faint star near Vega, which was not seen with the Lick telescope. In 1864, Winnecke found a small star at the same distance (55 seconds) from Vega, and not far from it; but Barnard's new companion is much fainter than Winnecke's, which is rated $14\frac{1}{2}$ magnitude. Curious to say, Struve's well-known companion (10th magnitude) is also at the same distance from Vega, but in a different quadrant. A faint and close companion to the bright star Procyon has been discovered by Schaeberle. It is evidently revolving round the bright star, and Dr. See finds a period of 40 years. He finds the masses of the two stars in the ratio of one to five. With Elkin's parallax of 0″·266, the semi-axis major of the orbit is 21·2 times the earth's distance from the sun, or a little larger than the orbit of Uranus. The combined mass of the two stars is about 6 times the sun's mass, and hence, as in the case of Sirius, the faint companion has about the same mass as the sun.

Numerous and interesting additions have been made to the list of variable stars. A very interesting variable of the type of Algol—"the slowly winking star"—was discovered at Potsdam by Messrs. Müller and Kempf. It varies from about 6·9 to 8·0 magnitude, and it has a secondary minimum of 7·35. These magnitudes give the relative brightness at the maximum and minima in the ratio of three, two, and one; and if the eclipses are central, it is easy to show that the phenomena may be satisfactorily explained by supposing two components of equal size, of which one is twice as bright as the other. It has been computed that the two stars revolve in their orbit in a period of 3 days, 23 hours, 49 minutes, and 32·7 seconds. The "Algol variable," W Delphini, has the greatest variation of this class known, namely 2·71 magnitudes—that is, the light of the star at maximum is about 12 times the light at minimum.

Next comes U Cephei, which varies 2·44 magnitudes. The variation of Algol itself is only 1·2 magnitude, and U Ophiuchi only varies 0·66 magnitude. Several other variables of the Algol type have recently been detected.

A variable, remarkable for its large variation and comparatively short period, was discovered in 1896 by Miss Louisa Wells near Schmidt's *Nova Cygni*. It varies from 7·2 to 11·2 magnitude, with a period of about 40 days. Here the light at maximum is 40 times the light at minimum. It lies about half a degree *north following* the star 75 Cygni.

A number of variable stars have been discovered by Mrs. Fleming at the Harvard Observatory from an examination of photographs of stellar spectra. A number of these interesting objects have also been found by Dr. Anderson, the discoverer of *Nova Aurigæ* and *Nova Persei*.

Dr. W. J. S. Lockyer has undertaken a discussion of the variations of the well-known variable star η Aquitæ. He found about 12,000 observations available for the purpose. Of these, over 7000 were made by the late Dr. Julius Schmidt, of the Athens Observatory, discoverer of the *Nova Cygni* of 1876. Dr. Lockyer finds that Argelander's mean value for the period cannot be much improved upon at present. He finds, however, that there are oscillations of a few hours in the times of maxima and minima. These cause a variation in the period between 7 days, 4 hours, 14 minutes, 40 seconds, and 7 days, 4 hours, 13 minutes, 28 seconds. Dr. Lockyer finds that one secondary maximum (among others) occurs 15 hours after the principal minimum. From spectroscopic observations of the star for motion in the line of sight, Belopolsky finds evidence of orbital motion in a period of 7 days, 4 hours, but he thinks that the variation of light cannot be caused by an eclipse (as in the case of Algol), as the time of observed minima does not coincide with the time of an eclipse in the computed orbit. He finds a somewhat similar result in the case of the variable star δ Cephei. A small variable star with a remarkably short period—known as U Pegasi—was discovered by Dr. Chandler in 1894. According to Chandler, the period is about 4½ hours, but from photometric measures made by Wendell, Professor Pickering makes it about 9 hours, or double the period found by Chandler. Another variable star of very short period was found by Professor Bailey in the globular cluster ω Centauri. The period is about 7 hours, 11 minutes, so that this curious star goes through all its light changes three times in 24 hours!

A large number of variable stars have been found in globular clusters. Professor Bailey has found at least 87 in the cluster Messier 3 in Canes Venatici. In some cases the variation of light is two magnitudes or more, and some have very short periods, only a few hours. In the cluster No. 5272 of the New General Catalogue, Bailey found 113 variable stars. In Messier 5, 85 have been found out of 750 stars, and in ω Centauri 122! Variables have also been found in other clusters, but in the well-known cluster in Hercules, Messier 13, there are very few, if any.

With reference to the probable temperature of stars of the "Orion type," it has been found by Kayser and Runge that in the spectrum of magnesium the triplet of lines known as *b* cannot exist at a very high temperature, and as they are absent in the spectra of Rigel and other stars of the Orion type, it has been inferred that the temperature of these stars must be higher than that of the electric spark. This agrees well with the great brilliancy of Rigel, notwithstanding its great distance.

The presence of oxygen has been determined in the spectra of β Crucis and β and ε Canis Majoris, also hydrogen, helium, and probably carbon and magnesium. Sir William Huggins finds that in stars whose spectra show strong lines of helium, such as Bellatrix and Rigel, there are dark lines which probably coincide with the lines of nitrogen.

As is well known, the nature of the substance giving the three well-known lines in the spectrum of the gaseous nebulæ has not yet been determined. For this unknown substance the name "nebulium" has been suggested by Sir William Huggins, and the term has been adopted by Sir William Crookes.

Professor Barnard finds that there is no trace of any nebulosity in any of the great globular star clusters, as seen in the great Yerkes telescope.

The 3-feet reflector, presented by Mr. Crossley of Halifax to the Lick Observatory, has been used for photographing stars and nebulæ, and with considerable success. The photographs show stars and nebulæ "far beyond the range of any visual telescope." Keeler thought that the total number of nebulæ which would be shown in the whole sky would much exceed 120,000! And it is remarkable that most of these nebulæ seem to be spiral.

It has been found by Schaeberle that photographs taken by Dr. Max Wolf with a Voightlander lens of 6 inches aperture, show as many stars as the 36-inch telescope of the Lick Observatory! This is remarkable, as Max Wolf's station is near the level of the sea, whereas the Lick telescope is placed at a height of about 4000 feet above sea-level. This shows the power of photography to reveal faint stars.

Several of those interesting and mysterious objects, known as "new" or "temporary stars," have been discovered during the last few years by Mrs. Fleming from an examination of photographs of stellar spectra taken at the Harvard Observatory (U.S.A.). One of about the 9th magnitude seems to have appeared in the constellation Perseus in

1887, but it could not be found with the telescope in after years. One in the southern constellation Norma appears to have reached the 7th magnitude. Its spectrum was similar to that of Anderson's new star in Auriga (1892), and, like that star, it seems to have faded into a planetary nebula. Another, of about the 8th magnitude, was found by Mrs. Fleming in the southern constellation Argo. It seems to have appeared between March 5 and April 8, 1895. The spectrum was apparently the same as that of the new stars in Auriga and Norma. Another star of the same kind was also found by Mrs. Fleming on photographs of the constellation Centaurus. It was about the 7th magnitude, and blazed out some time between June 14 and July 8, 1895. It was observed visually on December 16, 1895, by Professor O. C. Wendell, with a 15-inch telescope, and had then faded to the 11th magnitude. It was situated in the outskirts of a small nebula (N. G. Cat., No. 5253). The spectrum was *not* similar to those of the temporary stars in Auriga, Norma, and Argo; but, like those stars, "it appears to have changed into a gaseous nebula." Early in the year 1898, or possibly towards the end of 1897, a new star appeared in the constellation Sagittarius. It was detected by Mrs. Fleming on photographic plates taken in March and April, 1898. These photographs show that on March 8 it was about 4·7 magnitude, and on March 13, 5·0 magnitude, so that on those dates it must have been easily visible to the naked eye. On April 3 it had faded to 8·2 magnitude, and, with some slight fluctuations of light, remained about this brightness during the month of April. It was observed visually on March 13, 1899, by Wendell, and he estimated it 11·37 magnitude on the photometric scale. A photograph of the spectrum, taken on April 19, 1898, shows the hydrogen lines bright, and some other narrow bright lines, which appear to be identical with lines in the spectrum of Anderson's new star in Auriga. When observed by Wendell on March 13, 1899, its light was found to be nearly monochromatic (that is, of nearly one colour), showing "the chief nebular line," and a faint continuous spectrum. It would seem, therefore, that this star—like other "new" stars—has "changed into a gaseous nebula."

Another small "Nova," also discovered by Mrs. Fleming, appeared in April, 1899, in the constellation Aquila. It was of the 8th magnitude in April, 1899, and in July, 1900, it was found to be "a nebula of the 12th magnitude."

The great new star of 1901 will be described in the next chapter. The discovery of so many of these temporary stars in the last few years suggests the idea that the phenomena may not be so rare as is generally supposed. But unless a new star becomes clearly visible to the naked eye it might very easily escape detection. It is an interesting fact that most of these temporary stars have blazed out in or near the Milky Way. The principal exceptions to this rule are: the star of 76 B.C. in the Plough, the star recorded by Hepidanus in A.D. 1012, and the "Blaze Star" in Corona Borealis in 1866.

To explain the phenomenon of temporary stars several hypothesis have been advanced. Tycho Brahé thought they might be formed from the cosmical vapour of which the Milky Way was composed, an hypothesis which was supported by Kepler. Sir Isaac Newton seems to have thought that they were in some way related to comets. In 1865, Zöllner advanced the hypothesis that the phenomenon of a new star might be due to the sudden rupture of a crust beginning to form on the surface of a cooling-down star. This hypothesis was supported by Vogel in 1877. Huggins and Miller suggested that the outburst of light in the "Blaze Star" in Corona Borealis may have been due to a convulsion taking place in the body of the star, causing the evolution and combustion of hydrogen and other gases. Lohse, in 1887, suggested chemical combinations of gases cooling down as a probable cause. In the same year Lockyer advanced the theory of a collision between two meteoric swarms. In 1885 Mr. Monck suggested—with reference to the new star in the Andromeda nebula—that "as shooting stars are know to be dark bodies rendered luminous for a short time by rushing through an atmosphere, new stars are dark (or faintly luminous) bodies which acquire a short-lived brilliancy by rushing through some of the gaseous nebulæ which exist in space." A direct or "grazing" collision between two dark bodies has also been suggested as a possible explanation, the arrested motion being converted into heat. A *direct* collision between two large bodies moving in opposite directions seems very improbable, as the result would be the formation of an enormous nebulous mass which would not cool down for probably millions of years. The rapid fading away of the light of temporary stars seems directly opposed to such an hypothesis. A "grazing" collision is also open to a similar objection. A near approach of two dark bodies might, however, produce tides in their liquid interior which would probably cause an explosion in one or both bodies. M. Flammarion, the famous French astronomer, has suggested that a body surrounded by a hydrogen atmosphere, a comet for example, grazing a dark body enveloped in an atmosphere of oxygen would be sufficient to produce a tremendous explosion. Mr. Monck's hypothesis of a dark body rushing through a nebula, is perhaps as probable as any other, and it seems strengthened by the discovery of the nebula surrounding the new star in Perseus, an account of which will be found in the following chapter.

Should our sun in its journey through space pass through a mass of nebulous matter, its heat and light would be vastly increased by the friction produced; and "the heavens being on fire" the earth would be "burned up," and St. Peter's prediction of a general conflagration would at once be fulfilled.

Numerous other discoveries have been made in the years 1901 to 1903, and the following are some of the most interesting results which have been obtained.

Professor Campbell (Director of the Lick Observatory) finds with the spectrograph that the so-called "runaway star," Groombridge 1830, is approaching the earth with a velocity of 59 miles a second. The motion at right angles to the line of light shown by its large "proper motion" is considerably greater, probably 140 miles a second or more.[1]

From the radial velocity (or velocity in the line of light) of 280 stars measured with the spectrograph, Professor Campbell finds that the rate of the sun's motion is about 11·8 miles a second.[1] Professor Kapteyn deduces a velocity of 11·44 miles a second, so it would seem that this motion has now been satisfactorily determined. A curious result of Professor Campbell's inquiry is that "the fainter stars seem to be moving, on an average, more rapidly than the brighter."[1] This

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[1] *Astronomical Society of the Pacific*, April, 1901.

seems corroborated by the fact that of the 13 stars which have the largest proper motions (above 3″ per annum), 9 are fainter than the 5th magnitude.

Professor Max Wolf of Heidelbergh finds "a nest or cluster of nebulæ" in Coma Berenices, nearly due west of the star β, and preceding it about 13 minutes of time. No fewer than 108 nebulæ seem to be gathered together within an area not exceeding in extent that of the full moon. They are mostly small and nearly circular in form.[1] A cluster of nebulæ is certainly an unique object.

Sir David Gill finds that the spectrum of the remarkable variable star η Argûs contains lines which closely resemble lines in the spectrum of Nova Aurigæ.[2] This curious star would therefore seem to be a sort of connecting-link between the temporary stars and the long period variables. Mr. R. T. A. Innes found its magnitude 7·68 in 1900; 7·78 in 1901; and 7·72 in 1902; so that an increase of light has apparently not yet set in.

A remarkable variable of the Algol type has been discovered in Sagitta by Professor Schwab. It has a period of 3·38 days, and varies from 6½ to 9th magnitude. At maximum it is conspicuous in an opera glass, but at minimum it is quite invisible in such an instrument. Its position for

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[1] *Astronomische Nachrichten*, 3704.

[2] *Monthly Notices*, R.A.S., LXI., App. 3.

1900 is R.A. $19^h\ 14^m\ 26^s$, N. 19° 25'·4. The presence of a third body is suspected. A number of new variable stars have been discovered in the last three years, but they are mostly faint, even at their maximum light.

Dr. A. W. Roberts finds for the southern variable T Centauri, discovered by Colonel Markwick, a mean period of 90·3 days, and a variation from 5·2 to 9·0 magnitude.[1] This is a very interesting star, as it can be followed through most of its phases with a binocular field glass.

From "a rough attempt to determine the total light of the stars by direct observation," Professor Simon Newcomb finds that "the total light of all the stars is about equal to that of 600 stars of zero magnitude [like α Centauri or Vega] with a probable error of one-fourth of the whole amount."[2] From statistics relating to the number of the stars and nebulæ, the present writer computed that the total light was equal to 589 stars of zero magnitude (*Knowledge*, August, 1901). His article on this subject appeared several months before Professor Newcomb's paper was published.

From spectroscopic observations of nebulæ in the line of sight, Dr. Hartmann and Professor Keeler found that the nebula No. 4373 of the General Catalogue is approaching the earth with a velocity of about 40 miles a second. Hartmann

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[1] *Monthly Notices*, R.A.S., November, 1901.

[2] *Knowledge*, March, 1902.

found a slightly different velocity in the middle and the edges of some nebulæ, which indicate "relative motions in the nebulæ themselves."[1]

Professor Seeliger finds that stars of 11 or 11½ magnitude are comparatively few in number near the poles of the Milky Way, but are very numerous in the Galactic zone. This is also true for fainter stars, such as those seen by Sir William Herschel in his "gauges." Easton thinks that the stellar universe is of "a fairly thick lens shape, filled with stars which are much more densely congregated near the edges than near the centre of the lens." He thinks that the southern pole of the Milky Way is probably less rich in stars than the northern. Seeliger finds that the distance between the sun and the internal border of the Milky Way is about 500 times the distance of Sirius (parallax = $0''\cdot37$), and the external border 1100 times the same distance; and he thinks that the system probably contains from 27 to 41 millions of stars down to the 13th or 14th magnitude. He does not admit any appreciable extinction of light in our stellar system, but extinction might cut off the light of external galaxies.[2] This was suggested by the present writer in his book, "The Visible Universe" (1893), p. 322.

Experiments made at the Nice Observatory by Perrotin, on the velocity of light by the toothed-

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[1] *Nature*, April 24, 1902.

[2] *Knowledge*, July, 1902.

wheel method under improved conditions, give as the result of 1109 observations the final value of 299,880 kilometres, or 186,339 miles a second, with a probable error of less than 50 kilometres, or 31 miles. This result agrees closely with previous determinations. According to Perrotin, the value of the solar parallax, from observations of the planet Eros at Nice, gives 8·805 ± 0·011, and from this he deduces a value of 20″·465 for the constant of aberration, "thus confirming the value adopted by the International Astronomical Conference of 1896."[1] These results are also satisfactory, for we have 8·805 × 20·465 = 180·194325, and theoretically the product of the two constants should be about 180.

M. Lau of Copenhagen finds variation of colour in α Ursæ Majoris (the northern of the two pointers in the "Plough"). According to his observations, the colour varies from 2·7 to 5·3 (on a scale of 0 to 10) in a period of 50 days. The star is usually yellow, but slightly reddish at maximum.[2] About 25 years ago, Klein found a similar variation, with a period of 30 days.

On March 16, 1903, a small new or temporary star was discovered in the constellation Gemini by Professor Turner, at the Oxford Observatory. It was then about the 7th magnitude, and was found on a photographic plate. It was of a red

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[1] *Nature*, December 11, 1902.

[2] *Bulletin de la Soc. Astronomique de France*, March, 1903.

colour, and showed bright lines in its spectrum. It was afterwards found on plates taken at the Harvard Observatory (U.S.A.). These showed that on March 1 it was not brighter than the 12th magnitude, but on March 6 it was about the 5th magnitude. Its rise in brilliancy was therefore probably very rapid, as is usually the case with these remarkable objects. On April 4, 1903, Parkhurst found it about 9th magnitude. On August 17, Professor Pickering found that its spectrum had become that of a nebula. Its position for 1900 is R.A. $6^h\ 37^m\ 49^s$, N. 30° 2′ 38″.

The binary star δ Equulei has the very short period (for a visual double star) of about 5·7 years. Hussey finds, from spectroscopic observations, a parallax of 0″·071, which he thinks must be very near the truth.[1] The sun, placed at the distance indicated by this parallax, would, I find, be reduced to a star of about 5·8 magnitude; and as the star's photometric magnitude is 4·6, it follows that the star is about 3 times brighter than the sun. Its spectrum is of the second type (F). The star's brightness seems to agree well with its parallax and spectrum.

The star ϕ^2 Orionis (one of the stars in the "head of Orion") has been found by the spectrograph to be receding from the earth with the great velocity of about 60 miles a second![2]

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[1] *Astronomical Society of the Pacific*, April 10, 1903.

[2] *Nature*, May 7, 1903.

Professor Pickering finds that the total number of stars down to 6·6 magnitude is about 10,000; the number to 8·7 magnitude is, he thinks, about 100,000; to the 11th magnitude, about 1,000,000; and to magnitude 11·9, about 2,000,000.[1]

For the close pair of the triple and ternary star ε Hydræ, Professor Aitken finds a period of 15·7 years for the close pair. The spectrograph also shows it to be binary, and the observations seem to indicate that "the visual and spectroscopic binary systems are identical."

From photographs taken with the Crossley reflector at the Lick Observatory, Professor Schaeberle finds that the Ring nebula in Lyra and the "Dumb-bell" nebula are both spirals.

A number of new spectroscopic binaries have been found in the last few years. Among these may be mentioned α Equulei, η Orionis, ν Andromedæ, σ Geminorum, ζ Tauri, η Virginis, ε Aurigæ, τ Tauri, ψ Orionis, ο Persei, δ Aquilæ, θ Aquilæ, α Draconis, α Coronæ Borealis, β Arietis, and ε Ursæ Majoris. According to Vogel, the period of ο Persei is about 4·39 days, with a maximum velocity of about 65 miles a second. The Algol variable δ Libræ has also been found to be a spectroscopic binary, with a radial velocity varying from +23½ to −76 miles a second. For η Orionis, Adams finds a period of 7·9896 days.

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[1] *Annals of Harvard College Observatory*, vol. xlviii., No. v., p. 179.

The companion is relatively dark. "The range of velocity is very great, amounting to over 285 kilometres," or 177 miles a second! The star is also a telescopic double (3½, 4½: 1″·24), but there seems to be no relative motion in the visual pair.

Photographs taken with the Crossley reflector at the Lick Observatory show that the spectrum of Nova Cygni (1876) "has become continuous, and that the spectrum of Nova Aurigæ (1892) is "approaching the continuous type." Mr. Palmer, who took the photographs, says, "These complete and astonishingly rapid changes of spectral type observed in the cases of *Nova Cygni* and *Nova Aurigæ*, and likewise those observed in *Nova Normæ*, *Nova Sagittarii*, *Nova Persei*, etc., leave little doubt that the masses of these objects is small."[1] This seems to the present writer the only conclusion admissible.

Herr Kóstinsky, of the Pulkowa Observatory, has found an absolute parallax for the bright star β Cassiopeiæ, from observations by himself (with the prime vertical instrument) and by Dr. Nyrén, the mean result being 0″·14, with a probable error of ±0″·03. A parallax for this star was found by the late Professor Pritchard, at Oxford, by photography. His result was 0″·15. Herr Kóstinsky "arrives at the conclusion that the absolute value of the parallax of β Cassiopeiæ is, with great probability, very near +0″·1, and rather a little

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[1] *Astrophysical Journal*, October, 1903.

greater than less."[1] A parallax of 0″·1 would reduce the sun to a star of the 5th magnitude, and as the photometric magnitude of β Cassiopeiæ is 2·42, it must be a much larger sun than ours. Its spectrum is of the second type (F 5 G Pickering).

Adams and Frost find that the star ξ Persei is apparently receding from the earth with the great velocity of over 52 miles a second, and they think it may possibly be a spectroscopic binary, as most of the stars with the "Orion type" of spectrum have a low radial velocity.[2]

From spectroscopic observations of the spectroscopic binary β Aurigæ, M. Tikhoff, of the Pulkowa Observatory, has arrived at the conclusion that the system consists of two pairs, "each pair consisting of a star giving strong lines and another giving weak lines, and each element making a complete revolution about the centre of gravity of its pair in 19·1 hours." The period of revolution of both pairs round their common centre of gravity is $3^{d}\ 23^{h}\ 30^{m}{\cdot}4$.[3] This seems to be the first example found of a spectroscopic quaternary system.

From an elaborate investigation of the observations of the variable star ε Aurigæ, M. H. Ludendorff arrives at the conclusion that it is an Algol variable, with a period of either 27·12 years or

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[1] *Nature*, November 12, 1903.

[2] *Astrophysical Journal*, December, 1903.

[3] *Nature*, December 24, 1903.

54½ years. The middle of the last minimum was 1902, March 31. He finds the whole duration of light change to be about 2 years, the duration of minimum light 313 days, and the times occupied in passing from maximum to minimum and from minimum to maximum being each about 207 days.[1] According to Vogel, the star is a spectroscopic binary with probably a very long period.[2] But the spectroscopic measures do not seem to agree with Ludendorff's conclusion.

In an interesting and suggestive paper by Professor Arthur Schuster, on "The Evolution of Solar Stars," in the *Astrophysical Journal*, April, 1903, he considers that the difference between a solar star and one having a spectrum like Arcturus, "may not be one of age at all, but mass." "If the Arcturian star is one which is bigger, it will be able to absorb the hydrogen more completely, and the final state of equilibrium will be such that the hydrogen lines will be thinner than in the Capellan or solar star." He says this theory "gives an explanation of a very curious fact, which I venture to think has not so far been satisfactorily accounted for. In the case of double stars, it is often found that the brighter one is yellow, and gives a solar spectrum, while the smaller one is blue, and gives a hydrogen spectrum. The larger one, though it may have originally

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[1] *Astronomische Nachinchten*, No. 3920.

[2] *Astrophysical Journal*, April, 1903.

attracted more hydrogen to itself, will be able to absorb it more rapidly, and thus pass through the stages of spectroscopic evolution more quickly." This fact has always been a perplexing one in the theory of stellar evolution, and Professor Schuster's explanation seems a very probable one.

Mr. Joel Stebbins finds that the famous variable star Mira Ceti is receding from the earth with a constant velocity of about 41 miles a second, "and this is held to be strong argument against the theory that the light changes are due to the existence of a companion." Mr. Stebbins concludes, from the spectroscopic observations, that "the light changes are due to internal causes, which produce effects that are, as yet, unfamiliar to us."[1]

In December, 1903, Professor Schaeberle announced his discovery of a spiral structure in the great cluster in Hercules (Messier 13).[2] "Nebulous streams joining certain stars in curved lines could be traced up to the very centre of the cluster." There seems to be two spirals, one "clock-wise," and the other "counter clock-wise." "A similar structure on a much larger scale exists in the stars and nebulosity surrounding γ *Cassiopeiæ*," and in Schaeberle's opinion, "the majority of the stars—both bright and faint—within half a degree of γ *Cassiopeiæ*, belong to a single physical

[1] *Nature*, December 31, 1903.

[2] *The Astronomical Journal*, No. 552.

system." This tends to show that in many cases the bright and faint stars in the Milky Way are practically at the same distance from the earth.

Some experiments made by M. Fabry indicates a value for the "sun's stellar magnitude" of −26·7, or 60,000 million times the light of Vega. This differs but little from the value of −26·5, which I have adopted in the present volume.

XXIV

The New Star in Perseus

ON the evening of Friday, February 22, 1901, while returning home from the house of a friend in Dublin, about $11^h\ 40^m$ p.m., Greenwich mean time, I happened to look towards the constellation Perseus, and was astonished to see a bright star of nearly the 1st magnitude shining in a spot where I knew that no star visible to the naked eye had previously existed. Next morning I telegraphed to the Observatories at Greenwich and Edinburgh, and also to Sir William Huggins, the famous astronomer. In a reply from Dr. Copeland, Astronomer Royal of Scotland, he informed me that the new star had been discovered on the morning of February 22 at $2^h\ 40^m$ a.m., by Dr. T. D. Anderson of Edinburgh, the well-known discoverer of Nova Aurigæ in 1892. The new star was also independently discovered by Mr. Ivo F. H. C. Gregg at St. Leonards on February 22, at $6^h\ 40^m$ p.m., and by the Rev. T. E. Espin, the Rev. S. J. Johnson in England, and by Dr. Bonnel in Paris on the same evening. Also by Mr. E. B.

Frost in America, and Mr. A. F. Miller at Toronto, Canada. It seems to have been also independently discovered by Mr. Laursen-Nordvig in Denmark, and by Messrs. Kvasnikoff and Sviatsky in Russia. It was seen on the following evening, February 23, by Mr. H. Wake and Mr. W. B. Dodd at Whitehaven, England, and by several observers in France. Its rise in brightness must have been very rapid. Mr. Dodd stated[1] that on the evening of Thursday, February 21, he happened to look at Perseus, and was sure that up to 12 p.m. on that night there was no bright star visible in the spot where the new star blazed out within three hours afterwards. Three German astronomers, Messrs. Grimmler, Plassmann, and Schwab, also stated that they were observing the region on February 21, from 7^h to 10^h 30^m p.m., and think that no star brighter than the 3rd magnitude could possibly have escaped their notice. Mr. Espin states that he was observing that part of the sky on February 20, and was sure that the new star was not then visible. The region was photographed on the night of February 19 at Harvard College Observatory (U.S.A.), and the photograph shows stars down to the 11th magnitude, but no trace of the new star is visible on the plate. A photograph of the region, taken by Mr. Stanley Williams on February 20, about 11 p.m.—only 28 hours before its discovery by Dr.

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[1] *English Mechanic*, March 8, 1901, p. 77.

Anderson—shows no trace of the *Nova*, although it contains stars to about the 12th magnitude.

When first seen by Dr. Anderson—to whom the honour of its discovery is due—he estimated that it "somewhat surpassed the 3rd magnitude" in brightness, and was about half a magnitude fainter than the Pole Star, or about 2·7. He stated that he was observing another part of the heavens at the time, and happening accidentally to look towards the constellation Perseus, he at once saw that a new star had appeared in the sky. In a letter to a friend, Dr. Anderson remarked, "Oh, what an absurd sonnet is that in which Keats brackets together the discovery of an ocean, and the discovery of a new celestial world. As if the finding of any terrestrial sheet of water, however large, could be compared for a moment as a source of joy with the first glimpse of a new glory in the already glorious firmament."

The new star rapidly increased in brilliancy. On the evening of February 22, when first seen by the present writer, it was about the 1st magnitude, and later on the same night it was estimated to be still brighter by observers in America. On the next evening, February 23, it had further increased in brightness, and at the Harvard Observatory it was thought to be "brighter and bluer than α Aurigæ" (Capella). It was then a really brilliant object, and probably the brightest star in the northern hemisphere! On the evening of

February 24 I thought it fully equal to Capella; and on that day at Harvard it was seen with the 6-inch equatorial and its 2-inch finder in strong sunlight. On February 25 it had faded to nearly 1st magnitude, and on February 26 I estimated it as intermediate in brightness between Capella and α Persei. On March 1 it was reduced to about the 2nd magnitude, and on March 6 to about the 3rd. From that date it faded with some small fluctuations until March 18, when it had descended to about the 4th magnitude. From that time a series of the most remarkable fluctuations of light set in. On the evening of March 19 it had fallen a little below the 5th magnitude. On March 20 it had risen to 3½ magnitude, and on the 22nd it was again below the 5th magnitude. It was again about the 4th magnitude on March 23, and below the 5th magnitude on March 25. It again rose to above the 4th magnitude on March 26, and these curious fluctuations continued with more or less regularity, and with a longer period of variation, until the third week in May, when the star became so low on the northern horizon, and the twilight so strong, that further observations became very difficult. During the month of June, the observations show considerable fluctuations of light, and to a smaller extent during July also. In August the fluctuations of light were small, the estimates of magnitude ranging from about 5·7 to 6·5. During September and

October, the star's light seemed to fade slowly, with no violent fluctuations, from about 6·2 to 6·7. At the end of the year it had fallen to about the 7th magnitude. In March, 1902, it had faded to the 8th magnitude; in June, 1902, to the 9th magnitude; and in November, 1902, to about the 10th magnitude. In April, 1903, Professor E. E. Barnard estimated it 10½ magnitude, and on July 30, 1903, Professor Perrine found it 11·5 or 12 magnitude.

When first seen by Dr. Anderson he thought its colour was bluish-white, and it remained of a white or slightly yellow colour on February 23 and 24. It was of a pale yellow on February 25 and 26, and became orange at the beginning of March. The colour during the remarkable oscillations of brightness seems to have been orange at maximum and red at minimum. Early in 1902, Professor Barnard found it "greenish-white."

According to Professor E. C. Pickering, the spectrum of the new star was on February 22 and 23 of the Orion type, "nearly continuous, with narrow dark lines." On February 24 there was a remarkable change, the spectrum having then become like that of other new stars, that is, crossed by dark and bright bands, the principal dark lines being bordered by bright lines on the red side. The observed displacement of the hydrogen lines, from their normal position in the spectrum, seemed to indicate a relative velocity of 700 to 1000 miles a second, thus suggesting the collision of two bodies with high velocities; but these enormous velocities of colliding bodies seem contradicted by the fact that measures of the dark lines of calcium and sodium by Messrs. Adams, Campbell, Wright, and Stebbins in America indicate a velocity in the line of sight of only some 3 miles a second. The observed high velocities may have been, however, possibly due to an outburst of hydrogen gas from the body of the star. Remarkable changes were also observed in the spectrum during the sudden fluctuations in the star's light which took place in March, April, and May. An examination of photographs of the spectrum taken at the Harvard Observatory in July, 1901, showed that—like other new stars—it was slowly changing into a gaseous nebula, the "chief nebular line" being very bright. The nebular spectrum became more marked in August and September.

An apparent nebular aureole round the star was found on photographs by Messrs. Antoniadi and Flammarion in August, 1901, and this was confirmed afterwards by Max Wolf, Kóstinsky, and Von Gothard. This was explained as due to the exceptionally strong ultra violet rays emitted by the new star, rays for which the object glasses of the telescopes used were not corrected. The correctness of this explanation was proved by the fact that photographs taken by reflecting telescopes did not show the supposed aureole.

Dr. Max Wolf, while making an examination of the supposed aureole, discovered a faint trace of real nebula a little south of the new star. As his telescope was not powerful enough to deal with this faint object he suggested that it should be photographed with a large reflector. This was done by Mr. Ritchey at the Yerkes Observatory with a 2-feet reflector on September 20, 1901, and the photograph showed a mass of nebulous matter of great extent and of an apparently spiral form surrounding the Nova. This interesting discovery was confirmed by Mr. Perrine at the Lick Observatory by photographs taken on November 7 and 8, and from a comparison of his plates with the photograph taken by Ritchey, he found that some of the principal condensations of the nebula were apparently moving at the enormous rate of 11 minutes of arc per annum. Perrine's startling result was confirmed by Ritchey. This unheard-of motion in a sidereal object seemed to preclude the idea of a *real* velocity of the nebulous matter, and the theory was suggested by Professor Kapteyn and Dr. W. E. Wilson that the nebulous matter shone merely by light reflected from the new star. Assuming this to be the case, calculation showed that the observed motion would be accounted for by supposing that the new star had a parallax of about 0″·011, on a light journey of about 296 years! Perrine afterwards announced[1] that he

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[1] *Lick Observatory Bulletin*, January 14, 1902.

had found a photograph of the new star taken on March 29, 1901, on which the nebulosity was very visible. This "reflection theory" has been supported by Hinks and Seeliger, but other astronomers do not agree with this explanation.

Attempts to measure its distance from the earth have not proved very satisfactory. From measures made from small stars near it, Dr. Hartwig of Bamberg, and Dr. Chase of Yale College Observatory, found a negative parallax, which would mean that the new star is further from the earth than the comparison stars used in the observations. Bergstrand, however, finds from photographic plates an absolute parallax of 0″·033. This would imply a journey for light of about 99 years, and would fix the real date of the catastrophe about the year 1802.

Professor W. H. Pickering thinks that "As far as the observations go the collision theory has been rendered untenable, and the explosion theory has been corroborated."[1]

On one of the earlier photographs of the region taken at the Harvard Observatory a very faint star was found very close to the place of the Nova by Father Zwack of Georgetown College Observatory (U.S.A.). From measurements of photographs taken in the years 1890 to 1900, Professor Pickering finds that this small star was variable to the extent of about one magnitude, and that

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[1] *Astrophysical Journal*, XIII., 4.

its position agrees closely with that of the new star. The same small star was also found by Mr. S. Blajko on a photograph taken by him on January 30, 1899. Professor Pickering says, "We may therefore conclude that a star whose light varied from the 13th to the 14th magnitude was visible for several years within 1 or 2 seconds of arc of the Nova, the difference in position being less than the errors of measurement."[1]

The position of the *Nova* is for 1900·0 R.A. $3^h\ 24^m\ 24^s$, N. 43° 33′ 39″. It lies between the stars κ and ν Persei, a little nearer to the latter star, and a little to the north of the line joining these two stars.

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[1] *Harvard College Observatory Circular*, No. 66, October 31, 1902.

XXV

The Coming Comet

THE return of Halley's comet will take place in the year 1910. This is the most remarkable and interesting of all the comets with known periods. Its period is about 75 years, and its returns have been traced back to B.C. 11. Other returns were recorded in the years A.D. 66, 141, 989, 1066, 1145, 1223, 1301, 1378, 1456, 1531, 1607, 1682, 1759, and 1835. It is the comet depicted in the Bayeux tapestry as having appeared at the time of the Norman conquest of England in 1066. At this return it seems to have been of great brilliancy, as its head is described as being equal to the full moon in size! with a tail of about 60° in length. It was also very bright in the years 1145, 1223, and 1301. It was observed in 1531 by Pierre Apian at Ingolstadt, and is said to have been then of a "bright gold colour." In 1607 it was observed by Kepler and Longomontanus, and on this occasion its colour is described as "dark and livid," although in brightness it is said to have exceeded all the brightest stars, and even Jupiter, with a long and thick tail. At its return in 1682 it was well observed by Flamsteed, Halley, Hevelius, La Hire, and Picard. Halley having computed its orbit found that the comets of 1531, 1607, and 1682 were identical, and predicted its return in 1758–59. Lalande, assisted by Madame Lepaute, also computed the orbit, and predicted a return in the spring of 1759. Halley did not live to see his prediction fulfilled, but the comet duly returned, and was first seen by Palitzch, an amateur astronomer living near Dresden, on Christmas Day, 1758. Its appearance in 1759 was described by Dr. Nicholas Munckley as "large, but very ill defined," and "very evident to the naked eye," even in moonlight.[1] Fortunately its appearance will not be spoiled by moonlight in 1910. Its return in 1835 was computed by Damoiseau, Lehmann, Lubbock, Pontécoulant, Rosenberger, and Stratford. Rosenberger predicted the perihelion passage for November 11, 1835; Stratford for November 15, and Lehmann for November 26. This event actually occurred on November 16—a remarkable fulfilment of an astronomical prediction. It was first seen in August "almost precisely in the spot in which Herschel saw the planet Uranus." Admiral Smyth first saw it on August 24 as "a nebulous blot of indistinct form and misty appearance." On the 28th the nucleus was visible, and very distinct on the 31st.

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[1] *Philosophical Transactions*, R.A.S., 1759, p. 95.

On the 9th and 10th October an appearance of a luminous brush or fan accompanied the nucleus. On November 7, the head was seen by Struve to pass over a star of the 11th magnitude without dimming its light in the least, and some other similar cases were observed by the great Russian astronomer. The comet passed through perihelion, or nearest point to the sun, on November 16, after which it passed into the southern hemisphere and ceased to be visible in Europe. At first looking like a round nebula, it began to develop a tail on October 2. This tail rather rapidly increased, and was 4° or 5° long on October 5. It reached its greatest length—about 20°—on October 15, and then rapidly decreased. It also showed small tails or jets turned *towards* the sun. In February, 1836, Sir John Herschel, observing it at the Cape of Good Hope, said that the comet kept him up "*all* night and *every* night," and he stated, "It is altogether the most beautiful thing I ever saw in a telescope. The most surprising thing about it, however, is the *enormous* increase of its dimensions within the last week, being now more than triple the diameter which it had on the 20th instant, when I first observed it. A few days ago it threw out two feeble tails; it has none now."[1]

At the next return, in 1910, the comet will be very favourably situated for observation. According to present calculations, it will have, at the

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[1] *Monthly Notices*, R.A.S., 1836, p. 190.

end of October, 1909, the same theoretical brightness as when it was last seen by Dr. Lamont, with the Munich refractor, on May 17, 1836. At that time its position will be near the star 130 Tauri. Then, retrograding with a slow, southerly motion in declination, it will pass through the constellations Aries and Pisces in January, 1910. On June 12, the calculated position is close to the bright star Capella, and 5 days later it will be on the confines of the Lynx and Leo Minor. At this period the comet will attain its least distance from the earth—about 23 millions of miles. It will be most conspicuous during the first half of June in the absence of the moon (full moon on June 22, 1910). It will, of course, be closely watched by all astronomers, and its light will be examined with the spectroscope for the first time in its history.

Halley's comet moves in a very elongated ellipse, the eccentricity of the orbit being 0·967. Its perihelion distance is about 54 millions of miles, so that on its next return it will pass much nearer to the earth than it does to the sun, and it will probably be a pretty bright object. Its return may be confidently expected. As the poet says—

> "The star will come. It dare not by one hour
> Cheat Science, or falsify her calculation;
> Men will have passed, but, watchful in the tower,
> Man shall remain in sleepless contemplation;
> And should all men have perished in their turn,
> Truth in their place would watch that star's return."[1]

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[1] "Prudhomme." Translated by Arthur O'Shaughnessy.

XXVI

Immensity and Minuteness

WE are accustomed to consider the numbers dealt with in astronomy as vast and wonderful. And so they are. Even the nearest fixed star to the earth is placed at a distance so great that it seems impossible for the mind to imagine its reality. The distance of the sun is very great when compared with the terrestrial distances with which we are familiar; and when we try to imagine that the distance of Alpha Centauri is 271,000 times the sun's distance from the earth, our mind fails to grasp the idea of so vast a distance. The only way in which we can hope to gain even a faint idea of this enormous distance is to consider the time that light takes to reach us from the nearest fixed star. Coming from the sun in 8 minutes and 18 seconds, light takes about 4⅓ years to reach us from Alpha Centauri. And if this is the nearest of the stars, how can we attempt to imagine the distance of the farthest visible in the largest telescopes?

But these marvels revealed to us by the telescope are perhaps not more wonderful than the facts disclosed by the microscope, and those inferred by physicists with reference to the constitution of matter. According to the molecular theory of matter, all bodies—solid, liquid, and gaseous—are composed of an enormous number of molecules, all vibrating round a mean position. Some have disputed this hypothesis, and contend that matter may possibly be homogeneous and continuous, and not composed of molecules or atoms; but Cauchy has shown mathematically that if matter were homogeneous, and not molecular, there would be no dispersion of light through a glass prism. The existence, therefore, of the science of spectrum analysis seems to prove conclusively that glass, at least, is molecular in structure. And yet the molecules of which it is composed are quite beyond the reach of our most powerful microscopes. "Fine rulings on glass, whose distance apart is less than half of the wave length of light, are readily resolved with optical distinctness by our modern microscopes, while the intimate texture of the glass is apparently as far removed from resolution as with the unarmed eye." Professor Tyndall considered that the world of molecules and atoms lies, "in all probability, vastly farther beyond the range of the microscope than the range of the microscope at its maximum lies beyond that of the unaided eye." This is like the close binary stars recently discovered by the spectroscope, which are probably as far beyond the reach of our largest telescopes as an ordinary telescopic double star is beyond the reach of the naked eye. This marvellous minuteness of the molecules of matter seems as difficult to imagine as the vast distances of the stars.

Cauchy concluded, from optical experiments, that the constituent atoms of matter are so small that 400 million go to an inch. Clausius and Clark Maxwell found 500 millions from considerations of gaseous phenomena. From electrical experiments, Sir William Thomson (now Lord Kelvin) found 700 millions to the inch. Perhaps we may assume as a mean of these results that 500 millions of atoms placed in a straight line would measure an inch.

These atoms are, of course, quite beyond the power of our microscopes, as I have said; but let us consider some living organisms which can be seen with the microscope. Certain forms of infusoria are so minute that an individual specimen can lie between two divisions of an inch divided into 25,000 parts! Taking the height of a man at 6 feet, or 2 yards, a length of an inch would be for this microscopical creature equivalent to a distance of 50,000 yards, or about 28 miles, for a human being; and to such an animalcula, a globe of 23½ feet in diameter would be as large as the whole earth is to us! What would, then, represent the distance of the sun and of the nearest fixed star to such a creature? Taking the sun's distance at 92,800,000 miles, it would be represented by 3,270,000 inches, or over 51 miles, and the distance of the nearest fixed star by about 14 millions of miles! So that for even these microscopical quantities, the proportional distances of the stars would still be represented by enormous numbers. For an atom of matter of the 500 millionth of an inch in diameter, one inch would represent about 568,000 miles for a human being, or more than double the distance of the moon from the earth. So that on this scale the sun's distance would be represented by 164 inches, or 13 feet 8 inches, and the distance of the nearest fixed star by about 700 miles! Now, 700 miles is $\frac{1}{340}$ of the moon's mean distance from the earth. Perhaps the farthest visible star is not more than 340 times the distance of Alpha Centauri. If this be so, we may say that the diameter of the sphere containing the earth and moon—the earth's system, as it may be called—bears the same proportion to the diameter of the ultimate atom of matter that the diameter of the visible universe does to the height of a man. Although man's physical stature is, of course, very small compared with the extent of the visible universe, the ultimate atom is equally small when compared with the diameter of the lunar orbit. According to

Dr. Johnstone Stoney, the number of atoms contained in a cubic millimetre of solids and liquids is something like 10^{21}, that is, 1 followed by 21 cyphers! How many atoms are contained in the earth's mass? I leave this calculation to my readers.

XXVII

Light, Electricity, and the Ether

WHILE the illustrious Fresnel was proving, by experiments, that light was due to the vibrations of an ethereal medium which fills all space, the famous Ampère was investigating the laws which ruled the action of electrical currents, and thus founded the science of electro-dynamics. The idea occurred to Ampère that the ether of space which forms the medium for the transmission of light might also serve for the propagation of electricity, and this happy idea has been confirmed by modern researches. But the true relation between light and electricity was first suggested by the late Professor Clark Maxwell, and was developed in recent years by Hertz, who was the real discoverer of the principles of wireless telegraphy.

All bodies may be divided into two classes, namely, conductors, which convey electrical currents, and insulators, or those which do not conduct electricity. The latter are also called *dielectrics*. The old electricians thought that all insulators were the same, and acted in the same way in preventing the passage of the electrical current; but modern researches show that this is not the case. If we consider light as an electric phenomenon, we must conclude that it is propagated through an insulating medium, for the ether of space is certainly a dielectric. Maxwell's researches tended to show that currents were formed in dielectrics; but before his time this was not suspected. Maxwell, however, explained the apparent anomaly by stating that dielectrics do not prevent the passage of a current by means of a greater resistance than conductors, but by resistance of another kind.

According to Maxwell's views of the nature of dielectrics, the difference in the modes of action of the two bodies is somewhat similar to the difference between the action of a spring which we try to compress and the motion of a body through water or other resisting medium. The former may be called *elastic* resistance, and the latter *viscous* resistance. Dielectrics may, then, be compared to elastic solids, and conductors to viscous liquids. On this view, Maxwell supposed two classes of currents, namely, currents of displacement passing through dielectrics, and currents of conduction traversing conductors. The former are of short duration, but the latter continue as long as the electromotive force remains in action. The heating of a wire through which electrical currents are passing is thus explained by the friction due to viscosity.

Electrical currents become perceptible in three ways: (1) by their heating effects; (2) by their action on magnets and currents; and (3) by the induced currents which they produce. According to Maxwell's theory, the currents in dielectrics should give rise to similar effects. Why, then, are they not perceptible? The reason is that they are of small intensity and short duration. With a very rapid alternation of currents, however, their effects should become perceptible.

It is to this rapid alternation of currents that—according to Maxwell—light waves are produced in the ether; and by induction, these waves travel through space. The vibrations of sound are longitudinal, but those of light are transversal, according to the theories of both Fresnel and Maxwell.

These views, expressed many years ago, were, of course, purely theoretical, and it was necessary that they should be proved by experiment. According to the old views, electrical induction should be produced instantaneously; but, according to the new views, it should be produced with a finite velocity, namely, with the velocity of light. If such a velocity of propagation existed, it was, of course, very difficult to determine it experimentally, as the velocity at which light travels renders it—for short distances—practically instantaneous. This difficulty was, however, overcome by the eminent German physicist, Hertz, whose death at the early age of 37 has been recently deplored. Hertz's method of proof rests on the principle of the interferences of waves of different phase. This principle applies to all wave motion which is propagated with a finite velocity. It should therefore be applicable to electrical induction, and if, as was formerly supposed, it is propagated instantaneously, there would be no interference in the electrical waves; but if, on the contrary, it has a progressive motion, like light, the interference might be made perceptible by suitable experiments.

By some very ingenious experiments, Hertz has shown that electrical waves travelling along a wire can be reflected and refracted, like light, and that interference effects are produced by reflection. He also showed that the velocity of propagation through air is finite, and equal to that along a wire; but he did not succeed in measuring the actual velocity. M. Blondlot has, however, recently measured the velocity of the electrical disturbance along a wire, and finds it to be about 186,000 miles a second, or practically the same as that of light, thus proving the truth of Maxwell's theory. It seems, then, very probable that light and electricity are identical, or, at least, that they are different manifestations of the same phenomenon—a phenomenon due to wave motion in the ether of space.

The hypothesis that light is transmitted by wave motion—a theory now universally admitted—evidently necessitates the hypothesis of a medium in which these waves are propagated through space. Various views of the constitution of this medium, known as the luminiferous ether, have been advanced by eminent physicists. Some of the properties attributed to this hypothetical fluid are so anomalous that it is almost impossible for the mind to conceive the existence of such a medium. Sir John Herschel says, "Every phenomenon of light points strongly to the conception of a solid rather than a fluid constitution of the luminiferous ether, in the sense that *none of its elementary molecules are to be supposed capable of interchanging places*, or of bodily transfer to any measurable distance from their special and assigned localities in the universe." The famous Dr. Young also says, "The luminiferous æther pervading all space is not only highly elastic, but absolutely solid." Now, as our finite minds cannot grasp the idea of a solid which is impalpable to the touch and invisible to our sight—as the ether evidently is—any theory which would relieve us from the necessity of imagining, or trying to imagine, such an anomalous substance should be very acceptable to our finite intelligence. Such a theory was advanced a few years ago by Professor de Volson Wood, and as his views, which are very carefully worked out, seem to be mathematically sound, some account of his hypothesis of the constitution of the ether may prove of interest to the general reader.

Professor Wood assumes that the ether is gaseous in its nature, and, consequently, molecular in structure, a conception which seems more probable than the hypothesis which ascribes to it the properties of a solid. He starts with two assumptions, both of which are known to be true. These are: (1) that light is transmitted through space with a velocity of 186,300 miles per second; and (2) that the ether transmits 133 foot-pounds of heat energy per second per square foot from the sun to the earth. There is no doubt whatever as to the velocity of light which has been determined by various methods, all of which give results in close agreement. With reference, however, to the heat energy transmitted from the sun to the earth, Herschel found 71 foot-pounds, and Sir William Thompson (now Lord Kelvin) assumed 83·5 in his calculations; but recent researches by Professor Langley show that the real value is considerably higher, and his results indicate the number 133, the value adopted by Professor Wood. I may here remark that any theory which takes into account the limited velocity of light—for although very high, the velocity is evidently limited—commends itself at once to our favourable consideration. For no other theory of the constitution of the ether attempts to explain, so far as I know, the limited velocity of light. Were the ether an *absolutely perfect* fluid, we might reasonably expect that the velocity of light would be infinite, or, in other words, that its propagation through space would be, for all distances, instantaneous. That this is not so, suggests that the velocity is limited by the constitution of the ether in the same way that sound is limited in velocity by the constitution of the earth's atmosphere, or of the substance along which the sound is conducted.

Starting with the above two assumptions, Professor Wood computes from the known properties and laws of gases that the density of the ether is such that a weight of one cubic foot is the fraction of a pound represented by 2 divided by 10^{24}. With this density, a cubic foot of the most perfect vacuum which has yet been obtained by air-pumps would contain "some 200 million million times the quantity in a cubic foot of the æther." In other words, "a quantity of the æther whose volume equals that of the earth would weigh about $\frac{1}{20}$ of a pound," or about $\frac{4}{5}$ of an ounce. Professor Wood also computes that the pressure of the ether would also be very small—about one pound on a square mile. Far, therefore, from being a solid, the ether is, on this theory, an excessively attenuated gas, and such an hypothesis certainly seems more plausible than the anomalous theories which have been hitherto held.

The chief objection which has been advanced against a gaseous constitution of the ether is that even with a highly rarefied gas a retarding influence would be produced on the motions of the planets, which, in the course of time, would be easily detected by astronomical observations. But Professor Wood shows clearly that, with his computed density of the ether, its resistance to the motions of the planets and comets would be absolutely insensible—even in the course of ages.

According to the kinetic theory of gases, the number of molecules even in a small volume of an ordinary gas is enormous. According to Thompson, the probable number in a cubic foot of air is 17×10^{25}, an immensely large number. Even for such a rarefied gas as the ether is supposed to be, on Professor Wood's theory, the number of molecules would be very great. He computes the number at 10^{16}. Large, however, as this number is, the number given above for air is about 17,000 million times as large! From this result it would seem that the law of Ampère and Avogadro is not applicable to Professor Wood's hypothetical medium.

Assuming that the earth's atmosphere is subject to terrestrial attraction, and that it obeys the well-known gaseous law of Boyle and Marriotte, namely, that the density is proportional to the pressure, we can find the law of the decrease of density with distance from the earth, and hence the density at any given height above the earth's surface. At a certain point the atmosphere will become so rarefied that it would have the same density and the same tension as the ether. Professor Wood computes that this height is about 127 miles. This should be the extreme limit of the earth's atmosphere. By another method, however, he finds 169 miles as the extreme height of the atmosphere. Both results are, however, uncertain, for a uniform temperature is assumed for the whole height; and as we know that the temperature diminishes as we ascend, the assumption is incorrect. Assuming a probable law for the decrease of temperature, and considering the temperature observed by Glaisher in his famous balloon ascents, he finds a height of 86 miles. Under certain conditions, however, he finds that the height might be increased to 110, and possibly even to 120 miles. Observations of the height at which meteors become visible indicate in some cases a height of 100 miles or more, but the usual height is between 70 and 80 miles.

Although he considers the constitution of the ether to be gaseous and molecular, Professor Wood thinks "that the æther is a substance entirely distinct from that of the atmosphere—that the former cannot be considered as the latter greatly rarefied, as some have supposed." He finds by computation that the density of the ether at the surface of the sun and at an infinite distance from that luminary, is sensibly the same, and considers that, unlike the earth's atmosphere, "the density and tension of the æther may be considered uniform throughout space." It would be impossible for a wave of light to be propagated in air with the known velocity of light unless we suppose the temperature of the air to be raised enormously—something like 400 billion degrees of the Fahrenheit scale. Professor Wood also computes the specific heat of the ether, and finds it more than a billion times that of hydrogen, which has the greatest specific heat of all known terrestrial gases. He finds the ratio of elasticity of the ether to its density to be very great, compared with the same ratio in the case of air. His result is 8 followed by 11 cyphers. He also shows that the earth's attraction for the molecules of air lying near the limit of the earth's atmosphere "will exceed 500,000 the resistance of the æther; hence the molecules of air accompany the earth in its orbit as certainly as does the moon, and are far more rigidly bound to it than is its satellite."

A similar theory respecting the constitution of the ether has been advanced by Mr. S. Tolver Preston. He shows that the resistance offered by the air to a body moving through it is due to the comparatively slow motion of its molecules—about 1600 feet per second, or about that of a rifle bullet—and that consequently, even if its density were as low at that of the ether, it would still offer great resistance to bodies moving with planetary velocities. If we suppose the molecules of the ether to be endowed with a very high velocity, this resistance would vanish, as the equilibrium of the medium would not then be disturbed. He therefore concludes that the molecules of the ether are extremely minute, and moving with high velocities. Professor Wood estimates the "mean square velocity" at 286,000 miles per second. Their minuteness "is absolutely necessary to enable the ether to penetrate with freedom the molecular interstices of matter." Their high velocity is consistent with the hypothesis of a large amount of energy being stored up in the ether, for the energy of a moving body varies as its mass multiplied by the square of its velocity. A small body moving with a high velocity may therefore possess more energy than a much larger body moving with a small velocity. As, according to the kinetic theory of gases, the pressure exerted by a gas depends on the velocity of its molecules, the ether may have a high pressure without being dense or solid, as some have supposed it to be.

The low density of the ether found by Professor Wood has an important bearing on the question of the supposed extinction of the light of very distant stars by absorption in the ether—an idea advocated by the elder Struve and other astronomers. I have shown elsewhere that telescopic observations yield strong evidence against the existence of any extinction of light, at least so far as our largest telescopes are able to penetrate into space. Let us see what effect the ether of Professor Wood's theory would have on the light of very distant stars. We can solve this problem by comparing its effect with that of the earth's atmosphere on the light of the stars. Although the earth's atmosphere extends with constantly diminishing density to a height of 100 miles or more, its total effect may be assumed to be equal to that of a homogeneous atmosphere of about 5 miles in height, and of a density equal to that of the air at the surface of the earth. Now measurements with photometers of the same star at different altitudes above the horizon have shown that the absorption of light by the earth's atmosphere amounts in the case of a star in the zenith to only about a quarter of a magnitude. Assuming—as we are justified in doing—that the absorption of light is proportional to the density of the medium through which the light passes, and taking the density of the ether as computed by Professor Wood, I find that the thickness of the ether which would absorb the same quantity of light as the earth's atmosphere would be about 2×10^{23} miles, or 2 followed by 23 cyphers—an enormous distance. Let us see what this implies. Measures of parallax have shown that the average parallax of stars of the 1st magnitude is about

$\frac{1}{10}$ of a second. Hence the parallax of stars of the 16th magnitude—about the faintest visible in the great Lick telescope—would be, if their faintness is due to distance, about $\frac{1}{10000}$ of a second. This would indicate a distance of 2,062,650,000 times the sun's distance from the earth, or, in miles, nearly 2 followed by 17 cyphers. Hence it follows that the thickness of ether necessary to reduce the light of a star by only a quarter of a magnitude would be about one million (10^6) times the distance of stars of the 16th magnitude. We may therefore conclude that, on Professor Wood's theory of the constitution of the ether, there would be no extinction of light due to the ether alone, so far as the largest telescopes can penetrate into the depths of space. So far as our limited range of telescopic vision extends, we may consider the ether as practically transparent, the total loss of light being wholly due to our own atmosphere. Of course there may possibly be some extinction of light caused by meteoric dust is space, but this hypothesis has nothing to do with the ether or with the question of its constitution which we have been here considering.

In a paper read before the American Association for the Advancement of Science on August 13, 1898, Professor Brush announced the discovery of a new gas, which he calls etherion. It has "enormous heat-conducting capacity," and "its mean molecular velocity is 100 times that of hydrogen," and Professor Brush is inclined to believe that it is identical with the ether of space. But I do not know whether this discovery has been confirmed.

APPENDIX

BINARY STARS.

NOTE A.

Star.	Period.	Semi-axis major.	Hypothetical parallax.	Magnitude.	Spectrum.	Remarks.
	years	secs.	secs.			
Struve 3062 ...	104·61	1·3712	0·061	6·10	II.	
η Cassiopeiæ...	195·76	8·2128	0·243	3·64	II.	
γ Andromedæ	54·0	0·3705	0·026	(5)	I.	Magnitude estimated
Sirius ...	52·20	8·0316	0·575	1·58	I.	
9 Argûs ...	22·0	0·6549	0·083	5·49	—	
ζ Cancri ...	60·0	0·8579	0·056	4·71	II.	
Struve 3121 ...	34·0	0·6692	0·063	7·26	II.	
ω Leonis ...	116·20	0·88241	0·037	5·55	II.	
ϕ Ursæ Maj....	97·0	0·3440	0·016	4·54	II.	
ξ „ „ ...	60·0	2·508	0·163	3·86	II.	
OΣ 234 ...	77·0	0·3467	0·019	6·99	II.	
OΣ 235 ...	80·0	0·8690	0·047	5·56	II.	
γ Centauri ...	88·0	1·0232	0·051	2·38	I.	
γ Virginis ...	194·0	3·989	0·119	2·91	II.	F
42 Comæ ...	25·556	0·6416	0·074	4·38	II.	
OΣ 269 ...	48·8	0·3248	0·024	6·75	I.	
25 Can. Venat.	184·0	1·1307	0·035	5·00	I.	
α Centauri ...	81·10	17·70	0·944	0·06	II.	
OΣ 285 ...	76·67	0·3975	0·022	7·24	—	
ξ Boötis ...	128·0	5·5578	0·218	4·64	II.	
η Cor. Bor. ...	41·60	0·9165	0·076	4·98	II.	
μ^2 Boötis ...	219·42	1·2679	0·034	(6·5)	I.	Magnitude estimated
OΣ 298 ...	52·0	0·7989	0·057	6·80	II.	
γ Cor. Bor. ...	73·0	0·7357	0·042	3·93	I.	
ξ Scorpii ...	104·0	1·3612	0·061	4·16	II.	F8G
σ Cor. Bor. ...	370·0	3·8187	0·074	5·29	II.	
ζ Herculis ...	35·0	1·4321	0·134	3·00	II.	

BINARY STARS (*continued*).

Star.	Period.	Semi-axis major.	Hypothetical parallax.	Magnitude.	Spectrum.	Remarks.
	years	secs.	secs.			
β 416	33·0	1·2212	0·118	5·85	II.	
Σ 2173 ...	46·0	1·1428	0·089	—	II.	
μ^1 Herculis ...	45·0	1·390	0·110	(9·4)	—	Magnitude estimated
τ Ophiuchi ...	230·0	1·2495	0·033	4·88	II.	F
70 Ophiuchi...	88·3954	4·548	0·229	4·07	II.	Computed mass of system equals 6·368 times the sun's mass
99 Herculis ...	54·5	1·014	0·070	5·36	II.	Mass of system nearly equals sun's mass
ζ Sagittarii ...	18·85	0·686	0·097	2·71	I. (A2F)	Star 1·75 magnitude brighter than sun
γ Cor. Aust. ...	152·7	2·453	0·085	4·26	II.	
β Delphini ...	27·66	0·6724	0·073	3·72	II.	
4 Aquarii ...	129·0	0·732	0·028	6·03	II.	
δ Equulei ...	11·45	0·452	0·089	4·61	II.	
κ Pegasi ...	11·42	0·4216	0·083	4·27	II.	
85 Pegasi ...	24·0	0·8904	0·107	5·83	III.	
β 883... ...	5·5	0·621	0·1993	(7·8)	—	Magnitude estimated

NOTE B.

The area of the whole sky is 41,253 square degrees, or $41253 \times (3600)^2 = 534,638,880,000$ square seconds.

$$\text{Hence } \frac{534,638,880,000}{100000000} = 5345 \text{ square seconds for each star.}$$

Now, supposing each star to stand at the centre of a small square, we have the side of this square, or the distance between the two stars $= \sqrt{5346} = 73$ seconds. Or, generally, if N be the total number of stars in the sky, we have—

$$\text{Distance apart} = \sqrt{\frac{534,638,880,000}{N}}$$

for an equal distribution of stars.

Of course, the stars are *not* equally distributed, but the above gives their *average* distance apart.

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THE END

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Gore